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Experience of Presence in Virtual Environments

Christine Youngblut

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Preface

This work was performed in support the “Development and Assessment of ADL Prototypes” task sponsored by the Under Secretary of Defense for Personnel and Readiness, Readiness and Training Directorate under the general direction of Dr. Robert Wisher (OUSD/P&R). It partially fulfills the objectives of this task to use Advanced Distributed Learning (ADL) prototypes and other appropriate sources to develop an “engineering of instruction” that links specific instructional design alternatives to specific instructional outcomes and to assist in the cost and effectiveness assessment of ADL prototypes, including assistance in the design of assessment experiments, collection of assessment data, and documentation of findings.

Many researchers reviewed or added details to the information presented on their experimental studies. We are grateful for all such contributions. We also gratefully acknowledge those individuals who reviewed and provided comments on this document. These include research staff members Dr. Dexter Fletcher, Dr. Roger Mason, and Dr. Rob Johnston from the Institute for Defense Analyses (IDA).

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Executive Summary

While reviewing research on how to maximize the effectiveness of the use of virtual environments (VEs) for Department of Defense (DoD) applications, data were collected based on the role that the sense of presence plays in VE applications. The potential importance of presence is based on a common assumption that increasing the sense of presence experienced in a VE leads to improved task performance.

This document is intended as a resource document that presents the results of this data collection effort. It considers (place) presence, co-presence, and social presence. Nearly 70 different measures and over 100 experimental studies of various issues regarding presence are identified.

Few of the experimental studies have attempted to examine the potential relationship between presence and task performance. This small set of studies has used four different measures of presence and nine different types of performance measures. Out of 83 findings, 42 showed a significant correlation between presence and task performance, most in the expected direction. As yet, there is no evidence on whether the relationships that do exist are causal in nature.

Nonetheless, some conclusions are clear. Despite a decade of research, the role of presence in VEs is still unclear. There is no commonly agreed theory of presence nor are there common measures for this construct. There is some evidence that particular technological, tasks and personal characteristics can influence the extent of presence experienced in a VE. However, the critical question of whether manipulating presence can achieve improved task performance remains unanswered.

1. Introduction

1.1 Background

Presence is commonly referred to as the defining characteristic of virtual environments (VEs), that is, the characteristic that distinguishes VEs from other types of computer-generated simulations. The potential importance of presence lies in the common assumption that experiencing a higher sense of presence in a VE results in better performance, be that performing some task in a virtual world or the transfer of knowledge and skills gained in VE training to the real world.

Unfortunately, the sense of presence is not well understood. Despite a decade of research, we are still uncertain if there are any consistent relationships between presence and performance, much less whether such relationships are causal in nature. Although it is commonly agreed that presence is a multi-dimensional construct, there is no comprehensive theory of presence, much less agreement on how presence should be measured.

The Department of Defense (DoD) is already using VEs for some military applications and foresees a much wider range of applications for the future. Accordingly, the Institute for Defense Analyses (IDA) is undertaking an analysis program to determine whether current data are sufficient to identify factors that impact the effectiveness of such systems, starting with a focus on the potential role played by presence.

1.2 Purpose

Many groups are seeking a better understanding of presence. From its start, IDA's program has included pulling together the results of these efforts to build a picture of the current understanding of presence. This document does not detail the full scope of IDA's analysis program; this information is being reported elsewhere. Instead, the purpose of this document is to share the results of the information collection efforts and serve as a resource to other researchers.

Based on information collected through contacts with other presence researchers and literature searches, this document identifies over seventy different presence measures that have been used in experimental studies, as well as over one hundred experiments that have been conducted. Hopefully, this information will be useful for others investigating the topic of presence in VEs. Thus, the primary audience for this document is other presence researchers. Our intention by summarizing existing research is to provide a common reference ground that will allow existing results to be fully capitalized and support the cross-fertilization of ideas. VE system developers form a second audience. Here, we hope that the discussion on performance may provide some data that will help them determine the probable importance of presence for their particular application and, as necessary, important system factors and user characteristics to focus on.

Another major reason for releasing this document is to solicit feedback. We may have misinterpreted the information collected and missed important research efforts. We encourage the

research community to inform us of these mistakes and oversights. Please contact Christine Youngblut at youngb@ida.org with any additional information, or questions, you may have.

1.3 Document Structure

If this document purported to provide a full treatise on the sense of presence, it would start with a discussion on the various evolving theories of presence. Instead, commensurate with its role as a resource document, we refer you to the numerous theory-related articles available in the literature, including reviews by Schuemie et al. (2001), Draper, Kaber, and Usher (1998), and Riva, Davide, and Ijsselstein (2003).

However, it is necessary to start with a description of the different presence measures that have been proposed and used in experimental studies, what is known about their reliability and validity, and any relationships among these measures. The remainder of this document essentially consists of tables that summarize the results found in studies to date. First, studies that examined the relationship between presence and various technological, task, and personal characteristics are summarized. The final section summarizes those studies that have looked for a relationship between presence and task performance. Appendix A provides summary descriptions of all the experimental studies identified.

In the following, references in the text of this document are given in standard format. Those given in tables in Section 2, however, are shortened to cite just the first author of the referenced work. Additionally, tables in Sections 3 and 4 refer to the summaries of experimental studies presented in Appendix A. Since some of the works cited include more than one study, as appropriate, these references include the number of the study being discussed, for example [Snow, 1996 (3)] refers to the third experimental study reported in the cited paper.

2. Measures of Presence

The measurement of a construct such as presence should be based on an underlying theory about that construct. The relationships among the construct's components would be mathematically defined, as would its relationships with related constructs. This is not the case for presence. Indeed, the investigation of measures is providing valuable feedback into the development and refinement of a theory of presence.

Lacking an established theory, it is useful to consider other properties that presence measures should exhibit. These properties can serve as interim indicators of the value of particular measurement approaches.

2.1 Desirable Properties for a Presence Measure

Any ideal measure, whether related to presence or not, should be non-intrusive, that is, doesn't interfere with the task being performed or measurement itself. It should be free from participant or experimenter bias. Additionally, a measure should be easy to use, not imposing an unwarranted burden in terms of time and/or special equipment. In the case of presence, a measure also should be capable of measuring temporal variations in the construct being measured. The ability to record real-time changes in the sense of presence a participant experiences would help in understanding the effects of changes in any stimuli, as well as the effect of participant changes such as adaptation and fatigue.

These types of properties affect reliability and validity. A *reliable* measure is dependent only on the construct being assessed and produces repeatable results under equivalent circumstances. Thus, reliability concerns the degree to which a presence measure is free from variance arising from chance or irrelevant factors. Reliability is usually assessed in statistical terms based on the degree of consistency among independently derived sets of scores.

A measure is *valid* to the extent that it measures what it purports to measure and nothing else. Validity is harder to pin down than reliability, particularly for a construct such as presence that has no precise definition or underlying theory. Establishing the validity of a measure is a process of building confidence that the measure does, indeed, measure the construct in question. Face validity can be considered, that is, whether there is a logical or reasonable relationship between the construct and proposed measure. Additionally, a valid measure should vary in expected ways with related variables or constructs and, conversely, be stable with respect to unrelated variables. Corroborative evidence of validity can be sought by comparing the results obtained with different types of measures.

Sensitivity is a related issue. Assuming that a measure is both reliable and valid, it is important that it is capable of detecting any change in the construct being measured, in other words, it can measure an effect caused by manipulating a variable known to influence that construct. It may also be necessary for a measure to be multi-level sensitive so that, for example, it can differentiate among multiple levels of presence during a VE experience.

These are the types of properties that have been considered for some presence measures. Ellis discusses an additional property: the ability of a measure “to remain constant when its determinants covary in compensating ways” (Ellis, 1996, 251). He argues that this property is necessary to allow predicting both change and constancy when determinants change and, hence, may provide evidence on how particular technological or other factors can be traded-off against each other at need. This property depends on the independence of a construct’s determinants, something yet to be examined in the case of presence.

2.2 Types of Presence

In its most common usage in the VE community, the term “presence” refers to a person’s sense of physical location, that “of being” in a particular place. There is no standard recognized definition for presence. Most of the literature, however, proposes something similar to the following: “Presence is the subjective experience of being in one place or environment, even when one is physically situated in another place or environment.”

Researchers recognize additional types of presence: co-presence and social presence. Unlike the case with (place) presence, the literature does not provide any explicit definition of co-presence. Using terminology similar to that used for the definition of presence above, we propose: “Co-presence is the subjective experience of being together with others in a computer-generated environment, even when participants are physically situated in different sites.” There are several things to note about this definition. First, like presence, co-presence is a subjective construct and the definition explicitly supports distributed VE applications. Also, in using the term “others,” we do not restrict ourselves to all the participants being human. Some may be computer-generated agents.

Social presence in the context of computer-mediated communications is an active area of research addressing, for example, issues in organizational communications, use of teleconferencing systems, and the role of Internet-based virtual communities. Early seminal work on the potential social impact of telecommunications was performed by Short, Williams, and Christie (1972). The main points to note are that, in this context, social presence is a subjective phenomenon that depends on properties of the medium, the concept was developed to measure the ‘quality’ of a means of communication or, more specifically, to support comparisons between media for defined tasks. Most of the current measures of social presence for VEs are based on this early work, but some researchers have taken a different view. In this case, social presence goes a step further than co-presence to address social psychological ideas of personal interaction. Paraphrasing Biocca (1997), “Social presence occurs when users feel that a form, behavior, or sensory experience indicates the presence of another individual. The amount of social presence is the degree to which a user feels access to the intelligence, intentions, and sensory impressions of another.” This addresses more than a replication of face-to-face communication, reflecting awareness of another’s intelligence and intentions, and some sensory impression of the other.

In addition to those VEs where a computer-generated virtual world is intended to replace awareness of the real world, there is augmented reality to consider. Here computer-generated displays are superimposed on the real world. For these types of applications, Stevens et al. (2000) suggest a notion of object presence for “the subjective experience that a particular object exists in a user’s environment, even when that object does not.” Thus, a participant should experience a sense of being in an environment that is still different from the real world. Object presence presents a potentially complimentary component to other types of presence.

It is important to note that most researchers believe an ultimate measure of presence will be an aggregate of different components, for example, subjective and observed behavioral measures, and, depending on the application, may address multiple types of presence. Indeed, some of the questionnaires identified in the following already contain items addressing different types of presence. We have categorized them according to their primary function.

All these types of presence are considered in this document, although there are less data available about co-presence, social presence, and object presence than for (place) presence. There is only one example of an object presence questionnaire so, for convenience, this type of presence is included with the discussions on more general (place) presence.

2.3 Measurement of Presence

In identifying different presence measures, we start with subjective measures that rely on some type of participant self-report or scaling of a sensory experience. These include questionnaires, measures based on discriminating between environments, and some measures based on assessment of psychological factors.

More objective measures are identified next. These involve some form of observation or automated measurement of a participant's behavioral responses to a virtual experience. They also include measures based on physiological changes, and those that consider reactions such as reflex and socially conditioned responses, and post-interaction effects.

Many of the measures discussed below are regarded as immature. Few have seen extensive use.

2.3.1 Presence Questionnaires

Subjective questionnaires are the most common approach to measuring presence. Table 1 provides short descriptions of current questionnaires, specifying names where given in the literature.¹ Where appropriate, the table also indicates the extent of use of each questionnaire. This includes both experiments designed to evaluate the questionnaire itself and those where the questionnaire was used assess some aspect of presence.

The scope of each questionnaire is determined, however informally, by some underlying concept of presence. Some focus on technological characteristics (or more properly, on perceptual and/or physiological responses to those characteristics) and others on more cognitive issues. For those who regard *immersion* as simply a description of the VE technology used, there is concern that the former mix immersion and presence, in a way, preventing exploring the potentially complex relationship between the two (Slater and Steed, 2000a). Similarly, since most of these questionnaires claim to measure presence based on participant's opinions about the effects of factors likely to cause a sense of presence, Slater maintains that questionnaires based on technological factors cannot be used to investigate those self-same factors. However, Singer and Witmer's (1999) rebuttal is a convincing argument that their notion of immersion, as depending on a participant's perception and reaction to a VE, is a precondition of presence. At the very least, a description of the VE technology used is necessary to understand the results of experimental

¹ Some presence questionnaires are embedded in a larger questionnaire that addresses additional concerns. In these cases, Table 1 gives a brief indication of the overall scope.

Table 1. Presence Questionnaires

Questionnaire Name	Factor Analysis	Item Description	# Studies	Primary Reference
Igroup Presence Questionnaire (IPQ)	Yes	1 item assessing the general sense of “being there” and presence subscales: <ul style="list-style-type: none"> - Spatial Presence (5 items): Sense of being physically presence in the VE - Involvement (4 items): Attention devoted to the VE and the involvement experience - Experienced Realness (3 items): Subjective experience of realism in the VE 5 additional subscales: Interface Awareness, Exploration of VE, Predictability and Immersion, Quality of Immersion, Drama.	3	Schubert (2001)
ITC Sense of Presence Inventory (SOPI)	Yes	44 items, with subscales: <ul style="list-style-type: none"> - Spatial Presence (19 items): Sense of physical presence placement, and interaction and control over parts of the mediated environment - Engagement (13 items): Tendency to feel psychologically involved and enjoy the content - Ecological Validity/Naturalness (5 items): Tendency to perceived mediated environment as lifelike and real - Negative Effects (6 items): Tendency to feel adverse physiological reactions. 	1	Lessiter (2001)
Memory Characteristic Questionnaire (MCQ)	No	21 items, including several related to metamemory judgments concerning presence. Other items address qualitative differences between experiences in memory, attention, coherence of memories, FOV, and similarity among environments	1	Hullfish (1996)
Object Presence Questionnaire (OPQ)	Yes	32-item version of Witmer-Singer PQ, modified to reflect sense that an object exists in the participant’s environment, as opposed to the participant “being there.”	1	Stevens (2002)
Questionnaire VR	No	22 items, with 3 items related to presence, based on sense of being in the same room as task-related objects and experiencing the VE as a place visited.	2	Axelsson (2001)
Questionnaire on Presence and Realism	No	2 items, one rating sense of presence and other rating degree of realism.	2	Wiederhold (2001)
Reality Judgment & Presence Questionnaire	Yes	Subscales: <ul style="list-style-type: none"> - Reality Judgment (8 items): Relating to reality, realism, and presence - Internal/External Correspondence (6 items): Relating to interaction and presence - Attention/Absorption (4 items): Relating to concentration, attention to limited field of stimuli, and loss of a sense of passage of time. 	2	Baños (2000)
Slater-Usuh-Steed (SUS) Questionnaire	No	5 to 6 items based on: (1) sense of “being there” in the VE as compared to being in a place in the real world, (2) extent to which there were times when the VE became the dominant reality, and (3) extent to which a participant remembers the VE as a place visited, rather than as having seen computer-generated images.	25	Slater (1999)

Table 1. Presence Questionnaires (Continued)

Questionnaire Name	Factor Analysis	Item Description	# Studies	Primary Reference
Swedish Viewer-User Presence (SVUP)	No	150 items, 18 of which relate to presence covering interaction, awareness of external factors, sound quality, enjoyment, simulator sickness. Remaining items cover quality evaluations, attitudes, realism, and information from different modalities.	1	Larsson (2001)
University College London (UCL) Questionnaire	No	Subscales: - Reported Presence (7 items): Based on SUS Questionnaire - Reported Behavioral Presence (3 items): Feeling of acting as if in similar real world - Reported Ease of Locomotion (3 items): Whether movement was simple, straightforward, and natural.	4	Meehan (2001a)
Virtual Presence Questionnaire	No	Sub-questionnaires: - Virtual Presence: Based on Psotka's questionnaire - Social Virtual Presence (see Table 9)	1	Thie (1998)
VR Usability Questionnaire (VRUSE)	Yes	100 items. Includes subscale: - Sense of Immersion/Presence (10 items): Extent to which VR system allowed participant to feel part of or immersed in the VE. Remaining subscales include Functionality, User Input, System Output (Display), Consistency, Flexibility, Simulation Fidelity, and Overall System Usability.	1	JSC (2000)
Witmer-Singer Presence Questionnaire (PQ)	Yes	32 items, with subscales: - Involved/Control (11 items): A ability to control events in the VE and responsiveness - Natural (3 items): Naturalness of interactions and consistency of VE - Interface Quality (3 items): Relating to amount of interference or distraction from task performance and participant's ability to concentrate Additional subscales retained on theoretical basis, not yet used: Auditory, Haptic, Resolution.	32	Witmer (1994a)
[No Name]	Yes	Factors: - Sense of "being there" (1 item) - Engagement of human senses (5 items): Awareness of real world and completeness of visual, auditory, and tactile sensory engagement - Perceived fidelity of interaction (12 items): Impact of input device, ease of movement, comfort level, realistic depth portrayal, and enjoyment.	2	Barfield (1998)
[No Name]	Yes	Factors: - Spatial Presence (10 items) - Tactile Engagement (3 items) - Sensory Presence (3 items)	1	Biocca (2001a)

Table 1. Presence Questionnaires (Continued)

Questionnaire Name	Factor Analysis	Item Description	# Studies	Primary Reference
[No Name]	Yes	15 items, with presence subscales: (remaining items related to co-presence) - Presence in VE (3 items): Extent to which participant is psychologically engaged - Quality of VE (2 items): Extent of participant's presence in the VE and realism of the spatial transformation perceived by the participant - Task Difficulty (1 item): Difficulty of performing task.	1	Bystrom (1999)
[No Name]	No	4 items rating visual realism of objects, ability to perceive self/object locations, visual realism of overall environment, feeling on being in the environment.	1	Cho 2003
[No Name]	N/A	1 item related to presence, repeated for different types of display devices. Remaining items designed to capture information comparing visual display devices.	1	Deisinger (2001)
[No Name]	No	14 items related to presence, 4 items related to spatial layout, 5 items on object location.	1	Dinh (1999)
[No Name]	Yes	2 items querying presence, 9 items relating to realism as affected by stereopsis, head tracking, GFOV.	3	Hendrix (1996a)
[No Name]	N/A	7 visual analog scales from 0–100, including: extent participant felt he went into the virtual world, extent virtual world seemed like place seen or visited, and extent participant felt he was standing in a laboratory or in the virtual world.	3	Hoffman (1999)
[No Name]	Yes	Dimensions: - Immersion: Sense of immersion, involvement, and engagement - Parasocial Interaction: Concerned with moving between real and virtual environments - Parasocial Relationships: Concerned with feelings of friendship toward participants - Physiological Response: Concerned with physiological reactions - Social Reality: Concerned with comparisons on how virtual events might occur in reality - Interpersonal Social Richness: Ability to observe interpersonal communication cues - General Social Richness: Concerned with items such as impersonal/personal, unemotional/emotional, unresponsive/responsive.	1	Lombard (2000)
[No Name]	Yes	9 items, including 3 rating scales based on the concepts underlying the SUS Questionnaire, and two items related to the ambient environment. Additional items addressed factors that might be related to presence, such as lag.	1	Nichols (2000)
[No Name]	No	5 items related to presence, some similar to SUS Questionnaire	3	Prothero (1995a)
[No Name]	Yes	21 items on virtual and social presence; earlier 11-item version with factors: - Distractibility: Concerned with potential distractors outside the VE - Willingness to Suspend Disbelief: Deal with components or ecological affordances of the environment that control the depth of immersion - Concentration: Concerns effect of others on enjoyment, extent of surprise when HMD	1	Psofka (1993)

Table 1. Presence Questionnaires (Continued)

Questionnaire Name	Factor Analysis	Item Description	# Studies	Primary Reference
		removed - Simulation Sickness Effects: Concerned with occurrence of symptoms of nausea, disorientation, and wooziness. Additional items address realism, responsiveness, FOV, ability to visually search, sensory engagement, adaptation, and flashbacks.		
[No Name]	No	14-item questionnaire	1	Regenbrecht (1998)
[No Name]	No	Items addressing sense of being in the VE, additional items addressing co-presence	2	Romano (1998)
[No Name]	Yes	27 items grouped into dimensions: - Being there: "Being there" in the VE - Not being there: Concerned with the disappearance of mediation - Reflective Consciousness: Awareness of "being there."	1	Sas (2001)
[No Name]	No	2 items on object presence, 1 item on place presence, 2 items on co-presence	1	Schroeder (2001)
[No Name]	No	2 items on place presence	1	Tromp 1998
[No Name]	No	2 items querying sense of being in the same room as objects	1	Widestrom (2000)
[No Name]	No	2-item questionnaire	1	Wiederhold (1998)

studies. In their series of analyses, Schubert and his colleagues (Regebrecht, 2001, 1999) found evidence that presence and immersion are different constructs. Moreover, an exploratory path analysis showed one of the factors that predict that presence is, in fact, immersion. These conclusions were supported by an additional analysis by Lessiter (2000).

Two of the questionnaires identified in Table 1 differ from the others in a particular way. These are the ITC-SOPI, and Lombard and Ditton's questionnaire. Based on the belief that examining all aspects of presence is required to build a full understanding of the construct, both these questionnaires are intended as to be used across different types of media. Although the intent is to include VEs, currently they have been used only for such media as IMAX cinema, 3D TV, and video games.

As would be expected from their differing scope, questionnaires vary considerable in length and, as indicated above, several are structured into subscales intended to reflect different components or dimensions of the presence construct. In most cases, some type of correlation analysis has been used to identify groups of related items. These groups are usually called *factors*, where each factor accounts for a proportion of the variance across all the items. This type of analysis provides information about the relative importance of items, identifies unrelated items for removal, and, by looking at the total variance accounted for, can provide some indication of the completeness of a set of items. Table 1 identifies those questionnaires supported by such analysis. Ideally, the analysis should be repeated with several unrelated data sets, but this has occurred for only the IPQ and the Witmer-Singer PQ.

Most presence questionnaires use some type of semantic difference or Likert-type scale where each item is anchored by opposing descriptors. They differ in scale size, ranging from 5- to 11-point scales. Most questionnaires are scored by summing the item scores. When subscales are used, item scores are first summed with each subscale and then the subscale scores are summed. Subsequent data analysis requires the use of nonparametric statistics to cater for the use of ordinal scales. The Slater-Usch-Steed (SUS) Questionnaire avoids this problem by counting the number of items that have 'high' responses. Assuming that the responses are statistically independent so that the overall count has a binomial distribution, this allows the use of standard logistic regression techniques. As for the high-low threshold, Slater and his colleagues have found that using '6' and '7' (on a 7-point scale) as high scores works well, although Meehan (2001a) found using '5,' '6,' and '7' better differentiated between his study conditions and was more multi-level sensitive. Another issue related to scoring arises from the uncertainty of whether various factors are additive and of their relative importance.

In addition to the questionnaires identified in Table 1, Preston (1998) and Welch (1999) both rate presence using a 1-item rating scale.

In terms of the advantages of this type of presence measurement, questionnaires are easy to use. They require no special training on the behalf of participants or experimenters, and no special equipment. Assuming a good design, questionnaires should also be relatively free of experimenter bias. As indicted by the frequent use of subscales, they can be well suited for assessment of a multi-dimensional construct, as presence seems to be. Finally, on the positive side, questionnaires are unobtrusive, that is, their use does not influence a participant's task or the sense of presence experienced in a VE.

Perhaps the most significant disadvantage of questionnaires is that they require a participant to average, or in some way reduce their reporting of a construct that likely varies over the VE experience to an essentially static measure. An additional disadvantage, one common to most

post-experimental measures, is the need to rely on a participant's possibly inaccurate recall of the experience. These problems are exacerbated when presence questionnaires are not completed immediately following the VE experience. Sometimes participants are required to complete performance tests or other questionnaires, such as the Kennedy et al. (1993) Simulator Sickness Questionnaire (SSQ) first. Presence questionnaires are also vulnerable to subject bias. Thus data should be collected from a large number of participants, or some calibration of individual ratings (something that is rarely performed) is needed, to minimize the effect of individual differences. From the participant's perspective, they can be tedious to complete, and lengthy questionnaires may result in a lack of due consideration being paid to each item. Another disadvantage, identified by Schuemie et al. (2001), is that prior experience in rating stimuli on other aspects of concern can affect the subsequent rating of presence.

Some researchers are also concerned that presence questionnaires depend on a participant's understanding of the terms used and presence is poorly defined. Hendrix and Barfield (1996a, 1996b, 1995), however, have found that differently worded questions produced similar results, thus providing some evidence that this latter case may not be a major problem.

These advantages and disadvantages have different potential effects on the reliability and validity of presence questionnaires. Subject bias, for example, can be a crucial reliability issue. Another important form of reliability concerns the inter-correlation among items, which is usually reported in terms of a coefficient of reliability called Cronbach's alpha. Inter-item reliability has been calculated for several questionnaires, or questionnaire subscales. As shown in Table 2, the coefficients range from .51 to .94.

Table 2. Inter-item Correlations for Presence Questionnaires

Questionnaire	(Subscale)	Alpha	Reference
IPQ	Spatial presence	.85	Regenbrecht (2002)
	Involvement	.72	
	Experienced realness	.79	
ITC-SOPI	Spatial presence	.94	Lessiter (2001)
	Engagement	.89	
	Ecological validity	.76	
	Negative effect	.77	
Object Presence Questionnaire		.84	Stevens (2002)
Reality Judgment and Presence Questionnaire		.82	Baños (2000)
Witmer-Singer PQ		.88	Witmer (1994)
Virtual Presence Questionnaire		.69	Thie (1998)
Biocca's questionnaire	Spatial presence	.87	Biocca (2001a)
	Tactile engagement	.71	
	Sensory presence	.51	
Sas's questionnaire		.92	Sas (2001)

An alpha of .80 or higher is generally considered acceptable when measuring a unidimensional construct (see <http://www.ats.ucla.edu/stat/spass/faq/alpha.html>). So most of the values shown in Table 2 are not particularly encouraging, still, it is important to remember that virtually all presence questionnaires are regarded as under continual development and refinement. Lessiter et al. (2001), for example, report that the ITC-SOPI currently is in use in over 10 laboratories worldwide in an attempt to collect corroborative data.

Hendrix and Barfield (see references cited above) provide different evidence for the reliability of their approach to measuring presence. In this case, the same participants in three different studies using similar VEs gave highly consistent ratings for each question with the mean level of presence varying, for example, by no more than 1 point on a 100-point rating scale.

The discussion in Section 2.1 identified several issues that can be considered for building evidence for the validity of a measure. Table 3 identifies questionnaires whose validity is explicitly discussed in the literature and summarizes which issues have been considered in each case.

Table 3. Reported Evidence for the Validity of Presence Questionnaires

Questionnaire Name/Identification	Face Validity	Vary with Related Factors	Stable for Unrelated Factors	Comparison with Other Types	Consistency Across Studies
Hendrix's questionnaire	-	-	-	-	✓
Biocca's questionnaire	✓	-	-	-	-
ITC-SOPI	✓	-	-	-	✓
Sas's questionnaire	-	-	-	-	✓
SUS questionnaire	✓	-	-	✓	-
UCL questionnaire	-	-	-	✓	-
Witmer-Singer PQ	✓	✓	✓	✓	✓
Mania's questionnaire	-	-	-	-	✓
Tromp's questionnaire	✓	-	-	-	-

Face validity refers to the existence of a logical relationship between the presence construct and a measure. The consistency among the results of factor analyses mentioned previously is suggestive of face validity, but cannot speak to the completeness of the scope of individual measures. Some researchers have collected additional post-experimental data that provides more informal support, for examples see Hendrix (1996b), Tromp et al. (1998), and Usoh et al. (1999).

A recent set of studies that exploited the supposition that a person is expected to feel more presence in one type of environment than another offers additional, but conflicting, evidence for face validity. For the Witmer-Singer PQ, Allen and Singer (2001) found presence scores were able to distinguish between experiences in the real world and an equivalent virtual world, but this was not supported in an additional study conducted by Usoh et al. (2000). In a similar vein, Casanueva (2001) found that PQ scores did not distinguish between a VE designed for high presence and one designed for low presence. Although all these studies used some variation on a search task, they varied widely in the type of VE interfaces used. The first two used a single-user environment with a head-mounted display (HMD) and Casanueva had groups of participants collaborating using desktop displays. In two additional studies, the SUS Questionnaire did distinguish between a real and comparable virtual environment, and even distinguished between different real world conditions, see Usoh et al. (2000) and Mania and Chalmers (2000). One of these studies also failed to find a significant difference using the PQ.

The next type of validity concerns whether a presence measure varies predictably with related factors. Here we focus on two questionnaires to illustrate the type of support some experimental studies have offered for validity. These presence questionnaires, the SUS Questionnaire and the Witmer-Singer PQ, have seen the widest use with well over twenty studies each. Considering only technological characteristics, mixed or unexpected results were found nearly as often as expected effects. Of course, with the current limitations in, for example, frame rate and HMD

resolution, it is difficult to determine whether such failures are due to the technology or reflect on the questionnaires themselves. Determining the effects of any particular characteristic is further complicated by the unknown interactions between technological, task-related, and personal characteristics. Additionally, there may be unrecognized variables that have causal influences that act to mask the effect of the variable in question.

A valid measure also should be stable with respect to unrelated factors. Unfortunately, there are no data that consider this factor.

Comparing questionnaire results with those obtained using other types of presence measures is another way of gathering data indicative of validity. In this case, the SUS Questionnaire scores correlated with a measure based on discriminating between environments (Slater, 2000a), reported behavioral measures of presence (Slater and Steed, 2000a; Slater, Usoh, and Chrysanthou, 1995b; Usoh et al., 1999), and an observed behavioral measure (Slater, Usoh, and Steed, 1995a). Findings were mixed for the three studies that compared the University College, London (UCL) Questionnaire scores with either behavioral or physiological measures. Nichols, Haldane, and Wilson (2000) found more favorable results, with a significant positive correlation between the presence aspects of Nichols' questionnaire and a startle response measure, and a negative correlation with a background awareness measure.

With respect to looking for corroborative evidence among presence questionnaires themselves, all the research to date has focused on the SUS Questionnaire and the Witmer-Singer PQ. There are five studies to consider. Three studies, Sas and O'Hare (2001), Youngblut and Perrin (2002), and Huie, Youngblut, and Buck (2003) all found a significant positive correlation between the two. An additional study by Youngblut and Huie (2003), however, failed to find any significant relationship, at least when the SUS Questionnaire was assessed counting only item scores of '6' or '7' as a high score. If this level for a high response was relaxed to include '5,' there was a significant positive correlation between the two questionnaires. Usoh et al. (2000) found high SUS Questionnaire scores were consistently associated with high PQ scores, but this relationship did not hold for low SUS Questionnaire scores when reported after performing experimental tasks in the real world, and no relationship when the same tasks were performed in a virtual world. These results seem to indicate that these two questionnaires may be measuring some common element(s) of the presence construct. A comparison of Sas's questionnaire and the SUS Questionnaire also found a positive correlation (Sas and O'Hare, 2001).

2.3.2 Measures Based on Discriminating Between Environments

Another category of presence measures that includes subjective ratings is based on a participant's ability to discriminate between environments. Some of these measures require making a judgment between different conditions in a VE. Others are based on the ability to discriminate between virtual and real, or even imaginary, environments. Those that have been experimentally studied are identified in Table 4.

Table 4. Measures Based on Discriminating Between Environments

Basis of Measure or Identification	Description	# Studies	Primary Reference
Breaks in Presence (BIP)	Participant reports occasions when he transitions from experiencing the virtual world to experiencing the real world	1	Slater (2000a)
Free Modulus Magnitude Estimation	Participant provides an estimate of the level of perceived presence in each of a series of VEs	3	Snow (1998)
Paired Comparison	Participant identifies which of a pair of VEs produced the greater sense of presence and provides a rating of the size of the perceived difference between them	2	Welch (1996)
Virtual Reality Monitoring	Participant identifies environment (real, virtual, imagined) in which certain conditions occurred, and rates his confidence in the accuracy of this response	1	Hullfish (1996)

Slater and Steed's (2000a) virtual presence counter, Breaks in Presence (BIP), requires a participant to verbally report when he switches from experiencing the virtual world to experiencing the real world. (The participant is not asked to report transitions from the real world to the virtual world since this would require him to immediately break his state of presence in the virtual world.) The intent is to determine when the participant shifts attentional resources to signals belonging to a specific environment. A probabilistic Markov chain model is constructed to model the transitions and estimate the equilibrium probability of being "present" in the virtual world. Additionally, the data in raw form offer some possibility of accounting for differences in presence experienced over time or, at least, identifying factors or events that reduce the sense of presence. Although the BIP measure tries to minimize the extent its use will disrupt task performance, at the very least, the participant has to hold the requirement to report BIPs in memory. Of course, any memory lapse will lead to underreporting of BIPs.

The next two measures are based on *magnitude estimation*, a measurement method that has been used in human-related research for many years. For this method, a participant is presented with a series of stimuli and asked to assign a number to each stimulus based on his subjective impression of its intensity. Snow and Williges (1998) use *free-modulus magnitude estimation* to measure presence. This differs from the base method in allowing the participant to assign any appropriate value to the first stimulus and assign numbers to successive stimuli with respect to the first stimulus. The second measure, used by Welch et al. (1996), is based on a form of magnitude estimation that employs mean magnitude estimates, sometimes called paired-comparisons. It differs by asking a participant to make a comparison between stimuli, rather than comparing stimuli to some modulus. Accordingly, Welch asks participants to identify which of two VEs produce the greatest sense of presence and to indicate the size of the perceived difference. Welch is investigating whether asking the participant to rate the difference between a virtual and corresponding real world will provide an anchor that yields a more absolute measure of presence.

The final measure in this category, Virtual Reality Monitoring, is based on the decision process by which people distinguish between real, virtual, and imagined events, as represented in memory. Here, "Memory becomes the mechanism by which the quality of the experience, and the technology that contributes to the experience, are evaluated" (Hullfish, 1996, 1). Thus, Hullfish defines the virtual experience in terms of the artifacts it leaves behind. In particular, qualitative differences between memories from different environments should enable participants to

distinguish where certain events occurred. Presence is assumed to be related to the ability to correctly attribute memory sources.

These latter three measures share some common characteristics. Most importantly, they all assume that “reality” is the goal and this assumption may not hold for all VE applications. They do not measure presence directly, but assume that presence is related to some other construct, where the nature of this relationship is uncertain. These limitations aside, they all offer the advantage of a relatively simple mathematical formulation and Hullfish goes so far as indicating a method for eliminating some of the effects of individual differences when measuring presence.

The reliability of the measures identified in this section has not been explicitly addressed, although Snow found consistent results across three uses of his Free Modulus Magnitude Estimation method. There are some data about validity. Slater’s BIP, Snow’s Free Modulus Magnitude Estimation, and Welch’s Paired Comparison measures have all been used in assessing the effect of certain factors on presence. Expected results were found with the BIP and Welch’s measure, and for ten of the eleven factors examined using Snow’s measure. Welch et al. (1996) also found corroborative information when they quizzed participants about their understanding of the concept of presence, the degree of which their sense of presence changed during the virtual experience, and the extent to which the factors influenced their feelings of presence. The answers were consistent with the presence data. Finally, as indicated in the previous section, Slater (2000a) found a significant positive relationship between BIP scores and the SUS Questionnaire scores.

Four additional measures have been proposed, but no actual use has been reported in the literature. The first of these, rotation nulling, also derives from established human-factors research methods and exploits previous research into *vection*, the illusion of self-motion. It is based on the rest frame hypothesis that states a person maintains a subjective coordinate frame that, itself, provides the basis for determining position, orientation, and motion. Disturbances to this rest frame may result in the illusion of position and orientation, that is, presence and the illusion ofvection (Prothero and Hoffman, 1995b). Then, if presence arises from a switch in cues used to determine position and orientation, the level of presence corresponds to the level of identification with virtual cues over real world cues. Given the relationship withvection, presence can be measured by the extent of manipulation of the magnitude of inertial oscillation required to reduce conflicting inertial errors cues. The measure is intrusive, requires special equipment, and is limited to those applications that are expected to inducevection. Although it may be useful in providing insights into presence in a laboratory setting, more general use would appear limited.

Schloerb treats the degree of presence as a probability measure: “the degree of subjective presence is defined to be the probability that the person perceives that he or she is physically present in the given environment” (Schloerb, 1995, 65). When a series of real and equivalent virtual worlds are presented in random order, the participant must determine which type of environment he is in. Recognizing the limitations of current VE technology, Schloerb provides for control/sensory transformations imposed on the interaction interface and the transformation of the region of presence. Sheridan (1996) proposes a similar measure. In this case, the degree of presence is measured in terms of the amount of “noise” (more precisely, the extent of filtering operations) required to degrade the real and virtual worlds until they are indistinguishable, and the amount of noise is negatively related to the sense of presence. Because we don’t yet fully understand the pertinent attributes in which the environments differ, he recommends that noise is used to degrade multiple attributes simultaneously. These proposed measures suffer similar problems to rotation nulling, they are intrusive and more suited for laboratory uses.

Finally, Ijsselstein et al. (2000) and Stanney et al. (1998) have suggested the use of a variation of magnitude estimation called cross-modality matching as better suited to constructs that do not lend themselves to verbal scaling. Here, a participant would express his sense of presence by adjusting some parameter in a different modality (for example, the volume of an auditory signal).

2.3.3 Psychological Measurements

Just as theories of presence are moving beyond technological concerns to consider the role of cognitive factors, new measures that explicitly address concerns such as attention are being developed. To date, the literature reports on only one psychological measure that has been used to examine the effect of particular variables on presence, though three more have been the focus of empirical studies. These four measures are identified in Table 5.

Table 5. Psychological Measures

Basis of Measure or Identification	Description	# Studies	Primary Reference
Background Awareness	Awareness of details about various type of background music that have no contextual meaning to the virtual world experience	1	Nichols (2000)
Engagement	Difference in attentional resources allocated to real and virtual worlds when different stimuli are simultaneously presented in each	1	Darken (1999)
VR Situation Awareness Rating Technique (VRSART)	Function of factors such as supply and demand of attention resources, situation awareness, time in environment, sensory modality, display mode	1 ²	Kalawsky (2000)
Sas's questionnaire	Function of participant's creative imagination, ability to become absorbed and feel empathy, and cognitive style	1	Sas (2001)

The first three measures in the above table concern some aspect of attention as a measure of presence. Nichols' Background Awareness is the most straightforward and based on the assumption that a participant more deeply involved in a VE experience would be less likely to recall the ambient environment. Three different types of background music (classical, operatic, and blues) were played in the laboratory where the study was conducted. After the VE experience, participants' reported their recall of the changes between types of music using categories that were collapsed into a poor, moderate, or good value of recall. This measure has the advantage of being easy to administer. Some limited evidence for its validity is provided by a significant negative correlation with one of three presence-rating scales used.

Darken et al. (1999) have been pursuing the development of an aggregate measure based on sensorimotor and cognitive factors. They started by investigating the suitability of attentional and spatial comprehension as an initial pair of measurable components of presence. For attention, these researchers used a traditional dual-task type measure to assess the level of attentional resources paid to one stimulus based on attention paid to a second stimulus. In this case, different visual and auditory stimuli were presented simultaneously in the real and virtual worlds.

² Details not available.

Subsequently, participants were quizzed about the material presented in each environment, with the difference between real world and virtual world scores providing a composite dependent measure of presence. This Engagement score was significantly correlated with Witmer-Singer PQ scores (Lawson, 1998). The candidacy of spatial comprehension was investigated by looking for a relationship between performance on spatial tasks and presence. No relationship was found. Accordingly, of these two factors, Darken and his colleagues suggest only the engagement measure as a candidate for inclusion in an aggregate measure of presence. Of course, the use of dual-tasks is highly intrusive, again making this measure more suited for laboratory investigations into presence. However, both Nichol's and Darken's measures may offer the potential, at least to a limited extent, of a real-time measure of presence.

Just as for Nichols' measurement of Background Awareness, the last two measures in this category do employ data collection questionnaires, but are discussed here to differentiate them from the subjective questionnaires discussed in Section 2.3.1 that attempt a direct measure of presence. Kalawsky focuses on the impact of cognitive functions on presence; in particular, the demand on and supply of attention resources to achieve situation and spatial awareness. Presence is assessed as follows (Kalawsky, 2000, 10):

$$\text{Presence} = (\alpha; \beta; \chi; \beta_d; C; SA; \Delta SA; \gamma; \mu; \tau; \Delta\tau; \psi; I_{\text{qty}}; I_{\text{qual}}; T_e; \kappa; \sigma; \theta; d_m; t; \Delta t)$$

where:

α = demand on attentional resources	I_{qty} = quantity of information
β = supply of attentional resources	I_{qual} = quality of information
χ = concentration of attention	T_e = elapsed time in environment
β_d = division of attention	κ = sensory modality
C = space mental capacity	σ = degree of immersion
$\Delta SA, SA$ = (change in) situation awareness	θ = field of view from participant's eyes
γ = understanding of situation	d_m = display mode (binocular, monocular)
$\Delta\tau, \tau$ = (change in) spatial awareness	t = update rate
ψ = familiarity of situation	Δt = processing lag

Immediately after a virtual experience, a computerized questionnaire is used to collect participant data and the technical details listed above. Still in early stages of formulation, the researchers involved are working to validate this measure.

Sas and O'Hare are developing a measure of presence that caters for individual differences by focusing on cognitive factors they believe are associated with presence. Based on data collected in a preliminary study, they propose the following (Sas and O'Hare, 2001, 11):

$$\text{Presence} = f(\text{Creative Imagination; Absorption; Empathy} \rightarrow \text{Fantasy Subscale; K})$$

where: K represents symbolically important aspects not yet considered.

Some comments on the potential reliability and validity of this measure can be made, even though it has only been used in exploratory studies. Creative imagination, Absorption, and Empathy are measured quantitatively using well-established instruments whose validity has been demonstrated in other areas. Further, using their presence questionnaire, these researchers found significant correlations between Creative Imagination and presence, and between Empathy and presence. As implied in the above equation, the strongest correlation for Empathy occurred with the Fantasy subscale that questions a participant's tendency to transpose themselves into fictional situations. Sas and O'Hare also report a significant positive correlation between results using this presence measure and the SUS Questionnaire.

2.3.4 Physiological Measures

Physiological measures for presence were first mentioned in the early 90s, but have only recently been experimentally examined. A study by Jorgenson et al. (1997) showed that VE experiences can have a significant effect on changes in heart rate, skin conductance, and skin temperature. Meehan (2001a, 3) best stated the underlying premise: “To the degree that a virtual environment evokes presence, it will evoke physiological responses similar to those evoked by the corresponding real environment, and greater presence will evoke a greater response.” These measures do not attempt to measure presence *per se*. Instead, the extent of presence is assumed to be related in some way to the extent of change in some physiological characteristics. Table 6 identifies measures that have been used.

Table 6. Physiological Measures

Basis of Measure or Identification	Description	#Studies	Primary References
Δ Heart Rate	Mean heart rate _{Stress Env} – mean heart rate _{Normal env}	5	Meehan (2003, 2001a), Zimmons (2003)
	Baseline heart rate – final heart rate	1	Preston (1998)
	Percent change from baseline	1	Wiederhold (2002, 1998)
Δ Skin Conductance	Mean skin conductance _{Stress Env} – mean skin conductance _{Normal env}	4	Meehan (2003, 2001a), Zimmons (2003)
	Percent change from baseline	1	Wiederhold (2002, 1998)
Δ Skin Temperature	Mean skin temperature _{Stress Env} – mean skin temperature _{Normal env}	3	Meehan (2001a)
	Percent change from baseline	1	Wiederhold (1998)
Δ Respiration Rate	Percent change from baseline	1	Wiederhold (1998)

These measures derive from the current body of knowledge on how stress affects certain physiological characteristics and there is substantial experience in their use, for example, orienting effects, habituation, and required sampling rates are well understood. Most physiological characteristics are relatively simple in themselves, but all require special equipment and additional set-up time. The monitors are attached to a participant and require cables running from the sensors to special recording and analysis machines. In one series of studies, Meehan (2001a) found that participants reported these encumbrances as the greatest cause of breaks in the sense of presence experienced. An earlier study, Meehan (2000), however, found this was not a problem, noting that most participants reported forgetting that any special equipment was connected. Another experiment, see Pugnetti et al. (2000), found similar results. Noise from measurement devices also can be a problem that requires special handling. The measures also are application dependent, for example, measures based on stress are only useful when the virtual world includes scenes or events that are stress invoking. Additionally, these measures may be highly subject to factors unrelated to presence, such as the stress caused by participating in a VE experience or a participant’s current state of health.

Meehan (2001a) and Meehan et al. (2001b) found some support for the reliability of presence measures based on changes in heart rate, skin conductance, and skin temperature. These researchers found reliable changes in these physiological responses over multiple exposures, and that the measures consistently distinguished between environments that were expected to result in different levels of presence. With respect to validity, all the measures except for Δ Skin Temperature varied as expected with related variables (frame rate and presence of passive

haptics). The relationships between each of Δ Heart Rate, Δ Skin Conductance, and Δ Skin Temperature with reported presence and reported behavioral presence (these latter measured using the UCL Questionnaire) were investigated. Δ Heart Rate correlated best with both reported presence and reported behavioral presence, though this relationship was significant only in one (of two) studies in each case. Δ Skin Conductance also correlated with both reported measures, but significantly so only in one (of three) studies. No relationships were found for Δ Skin Temperature.

Looking across the work of these researchers for corroborating evidence is problematic. In addition to the usual differences in the VE technology, applications, participant pools, etc., these researchers use different measurement techniques and devices. Bearing this in mind, Wiederhold, Gevirtz, and Wiederhold (1998) provide additional evidence for the validity of Δ Skin Conductance, in that they found this measure varied predictably with display condition and changed significantly, as expected, during a virtual aircraft flight. Results for Δ Skin Temperature were also similar to Meehan's, that is, Δ Skin Temperature showed little change. Unlike Meehan, however, Wiederhold et al. and Preston (1998) also found little variation in Δ Heart Rate or Δ Respiration Rate. More recently, Wiederhold (2001) found a significant negative correlation between reported presence and each of Δ Heart Rate and Δ Skin Resistance.

Various researchers have suggested using additional physiological measures such as mental workload, muscle tension, eye scanning, and eye blink rate, but no actual presence measures based on these characteristics have been proposed to date.

Despite their problems, there are several reasons why this type of measure deserves further investigation. First, unlike the majority of the measures discussed previously, physiological measures allow real-time capture of data during a VE experience. This eliminates relying on the accuracy of a participant's recall of the experience and raises the potential for investigating how presence changes in response to changes in activity, environment, or mental state. The second important advantage of these measures is their freedom from participant and experimenter bias (assuming, of course, that participants do not employ any biofeedback techniques). However, there remains a lack of data on how the use of physiological measures can be widened to applications involving different types of stress, or even environments that are not intended to induce stress.

One interesting approach has been suggested by Slater (2002), who has discussed the possibility of using changes in physiological responses to identify the onset of Breaks in Presence (BIPs), see Section 2.3.2. This would serve to overcome some of potential disadvantage of the BIPs measure, for example, a participant having to keep in memory the need to report BIPs. No empirical results have been reported to date.

2.3.5 Observed Reactions

Observations of participants' reactions, or lack of reactions, also offer the potential for a measure of presence that is not dependent on the accuracy of a participant's recall of a VE experience or an "averaging" effect. As Slater and Usoh (1992) note, people can be unreliable witnesses of their own behavior, and external verification of the sense of presence is useful. Behavioral measures may also capture aspects of presence not included in subjective reporting that promote further understanding of the presence construct. Additionally, participants' behavioral responses to particular situations can reveal insights into the impact of VE technology. Tromp et al. (1998), for example, describe how analysis of video recordings of collaborative activities suggested that the

use of a desktop monitor with a small field of view (FOV) prevented seamless transition between individual and collaborative tasks. Observed behavior measures that have been used are shown in Table 7.

Table 7. Observed Reaction Measures of Presence

Basis of Measure or Identification	Description	# Studies	Primary References
Aligning Bodies	Observation of whether a participant moved real left hand to correspond with manipulation of virtual left hand	1	Slater (1994b)
Come-Back Rate	When required to wait, proportion of participants who chose to re-enter the virtual world rather than read a book	1	Thie (1998)
Extremity of Decision	Evaluation of whether average post group response was more extreme than pregroup responses	1	Thie (1998)
Fear Response	Observation of whether a participant seemed unbalanced or verbally reported reactions when required to walk on a virtual plank over a virtual chasm	1	Slater (1993a)
	Count of occurrences of 15 types of behaviors believed to be associated with moving near a real 20 ft drop	3	Meehan (2001a)
	Observation/reporting of whether a participant followed a virtual ledge around a virtual chasm or moved directly over the chasm to get to the other side	2	Slater 1995a), Usuh (1999)
Observed Walking Behavior	Observation of foot motion	1	Usuh (1999)
Pointing to Source	Ratio of angles when pointing to virtual cues that are misplaced from real world counterpart cues	1	Slater (1995b)
Socially-Conditioned Responses	Observation of whether a participant behaved “normally” in selecting familiar objects and in respecting others’ space	1	Usuh (1996)
Startle Response	Classification of a participant’s response to a randomly timed “startle event”	1	Nichols (2000)
	Observation of whether a participant tried to move out of the way when an object seemed to be flying toward the participant’s head	1	Slater (1993a)

Most of these measures are based on how closely reflex responses to social or threatening conditions in a virtual world match those in the real world. Two groups of researchers, one led by Slater and the other by Meehan, have examined the potential of Fear Responses as a measure of presence. Both used VEs that confront a participant with some type of pit or chasm. Slater’s group has also used observations of objects flying toward a participant’s face. This group is the only one that has examined Socially-Conditioned responses, in one study noting how participants responded to a familiar environment and the presence of other people. Another measure based on reflex responses, again examined by Slater and his colleagues, is based on a participant’s association between his real body and virtual representation of his body. In this case, only the participant’s right hand was tracked and aligned with his virtual right hand. The researchers observed whether the participant automatically moved his real left hand to mirror computer-generated movement of his virtual left hand.

The literature is not always clear on how observed reactions are operationalized as actual measures of presence. In most cases, it seems that a simple count of the number of participants’ reactions or responses is used. For example, Meehan defines fifteen types of pertinent behaviors, including movements and verbal exclamations, and sums the number of occurrences of each type of behavior to provide a composite measure of presence. One exception is the Pointing to Source measure based on conflicts between virtual and real cues. Presence was measured as the angular

discrepancy between the position of a radio in the real world and the position a participant points to as the location of the “matching” radio in the VE. A lower angular discrepancy is assumed to indicate less association with the virtual world, that is, less presence. All the measures in this category, but one, are based on observations taken during the VE experience. The odd man out is the Come-Back Rate measure. In this case, a participant’s choice to revisit a virtual world, rather than read a book, is taken as an indication of the extent of presence experienced during the first exposure to the VE.

In most cases, these measures have been treated as an independent measure of presence. Exceptions occur for Meehan (2001a) and Usoh et al. (1999), where the occurrence of response behaviors (treated as ‘0’ or ‘1’) is included as an item in the UCL Questionnaire. Also, Nichols’ Startle Response measure is included in a more general presence questionnaire (see Section 2.3.1).

These measures, at least the current set, are free from subjective reporting bias, easy to observe, and require little in the way of special equipment or experimental set-up. Most can be used to determine whether particular events or circumstances impact presence. However, the potential disadvantages, common to some of the other measures discussed, seem to outweigh these strengths. For all but Come-Back Rate, the primary problem is that they are highly dependent on the type of application, and/or require the introduction of non-task related special actions or effects to be added to the VE. Such additions may interfere with task performance and, inevitably, they interfere with the sense of presence being measured. In a similar vein, when presence is related to fear, it is uncertain whether the stressful event triggered presence, or presence was a prerequisite for fear to occur. As data collected by Slater and Usoh (1992) suggest, a participant who is least present for most of the VE experience is likely to be the most startled by a sudden and unexpected situation. Further, while those measures that count multiple behaviors may be able to distinguish between different levels of presence, their usefulness is limited by current understanding of the relative importance of different behaviors.

There is also a lack of data on reliability and somewhat mixed evidence for validity. Positive evidence includes the fact that participants who aligned their virtual and real bodies did report a higher level of presence (Slater, Usoh, and Steed, 1994b). Thie and van Wijk (1998) found a significant positive correlation between their Come-Back Rate and Psootka’s questionnaire. The Pointing to Source measure was sensitive to a related factor (use of dynamic shadows) and had a significant positive correlation with SUS Questionnaire scores. However, while Usoh et al. (1999) found positive correlations between various Fear Response measures and an expanded version of the SUS Questionnaire, Slater, Usoh, and Steed (1995a) found a negative relationship for at least one of these measures using a 3-item SUS Questionnaire, and in another experiment found no relationship between a fear response and presence, see Slater (1993a). Evidence for the validity of Meehan’s measure based on observation of characteristics behaviors was mixed; the measure consistently correlated with reported presence across three studies, but exhibited an inconsistent relationship with reported behavioral presence. Based on these results, Meehan does not recommend further use of the measure. Nichols et al. did find a positive correlation between their Startle Response measure and the rating of presence, but Slater and Usoh (1993a) found no relationship.

Several additional measures in this category have been suggested. Slater and Usoh (1992) have observed responses when a participant’s virtual body disappears (leaving only a virtual hand) and when he enters an upside-down room. The same researchers also have considered participant responses to events outside of the virtual world, such as an outside observer dropping a cup and saucer, or interrupting the participant to ask for the current time. Gestural and verbal responses to

other occupants in a virtual world could provide another example of a socially-conditioned measure. These types of observations, however, have not been used as actual measures and would likely suffer the disadvantages previously described.

2.3.6 Post-Interaction Effects

An additional category of presence measures discussed in the literature is based on the potential aftereffects of a VE experience. It is useful to include these in this overview, although no measures have been used in practice.

Barfield and Weghorst (1993) suggested a presence measure derived from context reorientation time or degree of disorientation experienced when a participant moves between virtual and real worlds. Welch (1997) elaborated on the same idea, giving two predictions: (1) The strength of the initial sense of presence in a VE is negatively correlated with the after-effects produced by the virtual experience; and (2) The greater the after-effects from a VE experience, the greater the increase in presence over the period of exposure. The first prediction arises from the idea that a VE provides a poor model of the real world that necessitates more sensory-motor adaptation and results in less presence. Alternatively, greater sensory adaptation may itself produce a strong sense of presence. Of course, it is unlikely that either prediction holds completely, and the relationship between aftereffects and presence is potentially complex.

The ultimate usefulness of after-effect measures is unclear. Such presence measures would be objective, unobtrusive (during the VE experience), and potentially multi-level sensitive. On the negative side, like most other measures, they cannot support real-time assessment of presence during a VE experience. Additionally, the danger that the measure is assessing the technological characteristics (such as frame rate), as opposed to presence, seems to be particularly high.

Existing research does not provide much insight into the potential validity of this type of presence measure. In some early research, Slater and Usoh (1992) found that a participant's self-reported ability to adapt to a novel circumstance did influence reported presence. Somewhat surprisingly, they found a negative relationship between the speed of adaptation and the sense of presence, and suggest that fast adapters may be better observers and, so, more likely to notice flaws in the virtual world.

2.4 Measurement of Co-Presence

Considering the expected importance of collaborative VEs, relatively little attention has been addressed to measures of co-presence and the role co-presence may play in the effectiveness of such applications. Slater et al. (1996a) identified two aspects of co-presence: (1) The sense of presence of other individuals, and (2) The sense of being part of a group and a process. Currently, questionnaires are the only type of measurement technique that have been used. Slater et al. (1996b) note the need for additional types of measures based on comparing observable behaviors in the real and virtual worlds, but no actual measures have been proposed to date.

Table 8 provides brief descriptions of current co-presence questionnaires. As this table shows, while some are treated as independent questionnaires, other are included as subsets in more general presence questionnaires. The questionnaires differ in length but are relatively short compared to most (place) presence questionnaires. Although Basdogan et al. (2000) state that they use the same strategy as Slater and his colleagues, their questionnaire pays more attention to interface issues asking, for example, whether the participant had thought to himself that he was

manipulating screen images rather than having a sense of presence with another person. Bystrom and Barfield (1999) also consider interface issues with five of their six items querying whether a participant's sense of co-presence was influenced by who controlled navigation and movement in the VE. The scope of Basdogan's et al. questionnaire is also broader than most in asking the extent to which a participant felt in harmony with his partner, thus touching on aspects of social presence. Casanueva (2001) takes this idea further with two items specifically addressing the sense of a group spirit. In all, Casanueva's co-presence questionnaire seems the most comprehensive.

Table 8. Co-Presence Questionnaires

Description	Independent Questionnaire	# Studies	Primary References
2 items based on how much a participant had a sense of being in the same room as his partner	No	3	Axelsson (2001, 1999), Schroeder (2001)
8 items, including whether a participant had a sense or memory of interacting with a person or a computer, a sense of the computer interface vanishing and working directly with another person, and similarity to working with a person in the real world	Yes	1	Basdogan (2000)
6 items addressing whether a participant had a sense of being with his partner and how having a partner affected the sense of presence, including the effect of controlling navigation and interaction	No	2	Bystrom (1999, 1996)
6 items addressing whether a participant had a sense of being in the same place as another, the emergence of a group/community, and a sense or memory of collaborating with real people rather than a computer or robot	Yes	4	Casanueva (2001)
Items addressing the sense of being in the same room with a partner, and being together	No	2	Romano (1998), Whitelock (2000)
2 items based on how much a participant had a sense of being in the same room as objects	No	1	Schroeder (2001)
3 items addressing the sense of being together with other people, being able to subsequently imagine being with other people in the virtual scene, and similarity of experience to experiences in the real world	Yes	2	Slater (2000b, 1999)
8 items addressing the sense of being with other people, working with people rather than a computer, similarity to real experiences, and sense of other humans interacting with the participant	Yes	1	Steed (1999)
2 items addressing the sense of being in the same room with a partner	Yes	1	Wideström (2000)

All items related to co-presence use a semantic differential technique with bi-polar anchors, although there is some difference in how co-presence measures are computed. Casanueva, Basdogan, Slater, and Steed and their colleagues all use a count of high responses. Bystrom and Barfield analyze data using non-parametric statistics, such as the Kruskal-Wallis procedure. Axelsson et al. (Axelsson et al., 2001, 1999; Wideström et al, 2000) simply sum the ratings across their two items.

After using his questionnaire in three different studies, Casanueva (2001) reports on inter-item consistency, citing a Cronbach's alpha of .79. The argument offered for face validity relies on the questionnaire being based on a set of three attributes that are termed "defining characteristics of co-presence," namely, that co-presence refers to a sense that others are present in a virtual world, being part of a group, and having a feeling that one is collaborating with real people. Further evidence for the validity of this questionnaire is offered by how the measure varied in expected ways with related variables; specifically, it was significantly related to a measure of group

collaboration and interaction. It was able to distinguish between VEs that were designed to evoke either a high or low sense of co-presence, and it varied as predicted with avatar appearance and functionality. However, the studies were consistent in finding no relationship between presence and co-presence. This was unexpected since Casanueva holds that presence is a prerequisite for co-presence.

No reliability data have been reported for the other co-presence questionnaires and support for validity is limited to whether the measures varied as expected with related factors and constructs. The questionnaire developed by Axelsson et al. has also been used in three studies. In this case, the two studies that had participants perform very different types of tasks, although using similar VE interfaces, both found a significant correlation between collaboration and co-presence, see (Axelsson et al., 2001, 1999). Findings for immersion, however, were inconsistent between the studies, see also (Wideström et al., 2000). Results concerning the expected relationship between presence and co-presence were also mixed. Two studies found significant positive relationships in an immersive environment, but not a desktop environment, while the third study found directly opposite results. Similar data are available for the remaining co-presence questionnaires. Though unsupported by multiple studies, Basdogan's et al. (2000) finding of an expected positive relationship with haptic feedback, and Bystrom and Barfield's (1999) finding of an expected positive relationship with task performance offer some preliminary indications of validity. Slater et al. (2000b) also found an expected positive relationship between co-presence and individual accord. This same study was the only one that found a significant correlation between presence and co-presence.

2.5 Measurement of Social Presence

With the exception of the questionnaire by Bailenson et al. (2001), current measures of social presence for computer-generated VEs are based on the work of Short, Williams, and Christie (1972). Short and his colleagues evolved their theories of social presence from research into efficiency and satisfaction with the use of different communication media. They regard it as a subjective quality of a particular medium, representing a cognitive synthesis of factors such as capacity to transmit information about facial expression.

As for co-presence, questionnaires are the only type of measure used for social presence. This is the least examined aspect of presence for computer-generated VEs. Only three different questionnaires that focus solely on social presence have been used in experimental studies, see Table 9.

Table 9. Social Presence Questionnaires

Description	Independent Questionnaire	# Studies	Primary Reference
5 items addressing whether a participant perceived himself as in the same room as another person, the other person was aware of him, and the other person as not real, sentient, computerized image	Yes	1	Bailenson (2001)
Judgment of 4 dimensions, unsociable/sociable, insensitive/sensitive, impersonal/personal, cold/warm	Yes	1	Sallnäs (2000)
Questions derived from Short, Williams, and Christie (1972)	Yes	1	Thie (1998)

[As mentioned in Section 2.4, the co-presence questionnaires of Basdogan and Casanueva include questions relating to social presence, but these researchers do not report on social presence as a separate construct. Lombard's (place) presence questionnaire also includes item relating to social presence but, again, no data pertinent to social presence have been reported.]

The questionnaires in Table 9 all use a semantic differential technique with 7-point bipolar scales. Bailenson's et al. questionnaire is similar, in part, to the SUS Questionnaire in asking whether another individual was perceived as being in the same place as the participant. Other items concern the participant's assessment of the "reality" of that individual. A particularly notable point about this questionnaire is that the researchers administered the questionnaire while a participant was still in the VE. In the study reported, a scale was hung in space over an avatar's head and an experimenter asked each questionnaire item verbally. This approach seems likely to capture more accurate reactions than when a questionnaire is administered after the VE experience, although simply answering questions might impact the extent of social presence being experienced.

There are scant data about the reliability and validity of these measures. The only data found in the literature for reliability concerns Bailenson et al.'s questionnaire, which yielded a Cronbach's alpha of .83. For validity, the lack of effect of the manipulation of social presence on Thie and van Wijk's (1998) social presence questionnaire results raises some doubt about its face validity, as well as its ability to vary as expected with related variables. Even so, results using this questionnaire did have a significant positive relationship with their Virtual Presence Questionnaire, although no relationship with the Come-Back Rate measure (see Section 2.3.5).

Recently, Biocca (2001b) has proposed a set of criteria and scope conditions to address weaknesses in past theories and measures, and to provide criteria for a measurement theory of social presence. No details about any specific measure are available at this time.

2.6 Relationships Among Different Types of Presence

Are (place) presence, co-presence, and social presence themselves related? There is no consensus on an answer to this question. Bystrom and Barfield (1999) argue for the independence of presence and co-presence based on the fact that the presence or absence of another person does not affect our sense of presence in the real world. Slater et al. (2000b) describe presence as a prerequisite for co-presence, where self-representation, the possibility of interaction and exchange of information are determinants of co-presence, and co-presence itself is a logically orthogonal attribute of presence. They also posit a relationship between co-presence and task-related characteristics such as collaboration. Casanueva (2001), Romano, Brna, and Self (1998), and Tromp et al. (1998) support these views, although Casanueva considers a relationship between co-presence and communication, while Tromp and his colleagues go a step further than Slater et al. in stating that co-presence is a prerequisite for collaboration, focusing on issues of group and individual accord. Thie and van Wijk (1998) describe social presence as a sub-mental model of presence.

Here we look a little further at some of the findings reported earlier in this section, focusing on the visual display mode that was the experimental factor in most of the studies. This serves to illustrate how consideration of particular characteristics can allow better comparison of results across studies. In two studies, Axelsson et al. (2001; 1999) found a significant correlation between presence and co-presence when a Cave-type projection screen display was used that was not present when desktop monitors were used to display the virtual world. Bystrom (1999),

Casaneuva (2001) in four separate studies, and Tromp et al. (1998) also found no relationship between presence and co-presence when desktop monitors were used for the visual display. Wideström et al. (2000) found the opposite, with a significant relationship, direction not stated, only when the visual display was a desktop monitor, and no relationship when the participant was in the real world or using a Cave display. Slater et al. (2000b) and Steed et al. (1999), however, found a positive relationship between presence and co-presence that was independent of whether an HMD or desktop monitor was used for the visual display. In general, of the 10 studies that looked for a relationship between presence and co-presence, most failed to find any significant correlations, though the role of the visual display device used is unclear. However, this generalization may not be meaningful. Only Slater and Casanueva used similar presence and co-presence questionnaires; the measures used by the other researchers varied considerably. Other important differences among the studies include the participants' degree of control over interaction with the shared virtual world, and the type of virtual world and task.

Only one effort has provided data about the potential relationship between presence and social presence. In this case, Thie and van Wijk (1998) found a significant positive correlation between the two.

In all, the extant empirical data are insufficient to confirm or deny any general relationships among (place) presence, co-presence, and social presence.

3. Studies Examining Characteristics that May Influence Presence

This section summarizes the results of experimental studies that investigated the potential relationship between various technological, task, and personal characteristics with presence. It consists largely of a series of tables that identify relevant studies and their findings. It is important to note that most of these studies were conducted under greatly differing conditions: different VE hardware and software systems, different tasks, different types of participants, and different measures of presence. Such details are given in Appendix A. Consequently, the fact that two or more studies found similar results for a particular characteristic *may* serve as substantiating data about the relevance of the characteristic in question or *may* imply that different presence measures are, in fact, measuring the same underlying construct. Of course, similar results may be coincidental or due to other factors. In the following, when we draw comparisons across different studies, the reader is advised to refer to Appendix A for more information about the particular studies discussed.

Further, it must be noted that, in most studies, the VE interface devices used were relatively primitive. For example, when immersive visual displays were used, the field of view and resolution were very poor, and any force-feedback was generally delivered to a single finger. Results may differ as VE interface technology matures over the next decade or so. Perhaps more importantly, it must be stressed that the vast majority of the tasks that participants were asked to perform were simple ones and not representative of the scope and complexity of the full range of anticipated use of VEs.

3.1 Technological Characteristics

Technological characteristics are concerned with how VE interfaces present a virtual world to a participant. They are not limited to hardware and software issues such as the frame rate, use of head tracking, or type of navigation mechanisms provided. They also include more qualitative factors such as the level of abstraction used in representing the virtual world and the extent of avatar realism.

The first of the following tables, Table 10, identifies experimental studies that examined the effect of technological characteristics on (place) presence. As can be seen, a wide range of characteristics has been examined. Most attention has been paid to the type of visual display used. Here, of twenty-two findings (number of displays conditions multiplied by the number of presence measures used), thirteen (59%) found that the more immersive types of display were positively correlated with presence. The remaining findings fail to show any significant effects. The types of displays range from 5-wall Cave displays to standard desktop monitors. Looking at the consistency of findings using different presence measures, Alexsson and his colleagues found a consistent positive relationship (five out of five findings) using their VR Questionnaire. However, the seven findings given for the SUS Questionnaire are less clear, with only one finding of a significant positive effect of the level of immersion on the sense of presence

Table 10. Relationships between Technological Characteristics and Presence

Factor	Conditions	Significant Effect	Presence Measure	Appendix A Reference
Audio cues	Present, absent	Yes (present)	Engagement score	[Darken, 1999 (1)]
	Present, absent	Yes (present)	Dinh's questionnaire	[Dinh, 1999]
	Present, absent	No	Engagement score	[Lawson, 1998]
	Present, absent	Yes (present)	VE, RE quizzes	[Lawson, 1998]
	Present (spatialized), absent	Yes (present)	Hendrix's questionnaire	[Hendrix, 1996b (1)]
	Spatialized, non-spatialized	Yes (present)	Hendrix's questionnaire	[Hendrix, 1996b (2)]
	Present, absent	Yes (present) (HMD users)	Startle response	[Nichols, 2000 (1)]
	Present, absent	No	Background awareness	[Nichols, 2000 (1)]
	Present, absent	No	Nichol's questionnaire	[Nichols, 2000 (1)]
	Present, absent	Yes (present)	Magnitude estimation ratio-scale	[Snow, 1996 (2)]
Avatar realism	Present, absent	Yes (present)	Rating scale	[Welch, 1999]
	Present, absent	Yes (present)	Romano's questionnaire	[Whitlock, 2000]
	Realistic, basic	No	2-items on place presence	[Tromp, 1998 (2)]
Collision response	Elasticity (1 0, 0.7), friction (0.7, 0.0), shape (true shape, ellipsoid)	Mixed (friction) ³	6-item SUS Questionnaire	[Uno, 1997]
Color	Matched to real location, to incorrect location	No	SUS Questionnaire	[Slater, 1995c]
	Color quality	Yes (high quality) (1 item)	Barfield's questionnaire	[Barfield, 1993 (1)]
Detail (level of)	Fish moving, fish not moving	Yes (moving)	Cho's questionnaire	[Cho, 2003]
	Fish with deformations, no deformations	Yes (deformations)	Cho's questionnaire	[Cho, 2003]
	High, low detail	No	Dinh's questionnaire	[Dinh, 1999]
	High polygon model, low polygon model	Yes (high polygon model)	Cho's questionnaire	[Cho, 2003]
	Complex fish behaviors, simple fish behaviors	Yes (complex)	8-item PQ	[Shim, 2001]
	Abstract terrain, realistic terrain	No	PQ Total and all subscales	[Singer, 1997]
	High, medium, low	No	Magnitude estimation ratio-scale	[Snow, 1996 (3)]
	Colored/textured objects, monochrome with no texture	No	Socially-conditioned responses	[Usch, 1996]
Display resolution	High scene detail, low scene detail	Yes (high detail)	Paired comparison	[Welch, 1996 (1)]
	High scene detail, low scene detail	Yes (high detail)	Paired comparison	[Welch, 1996 (2)]
	640 × 480, 320 × 200	Yes (640 × 480)	Magnitude estimation ratio-scale	[Snow, 1996 (1)]

³ Increasing with correct shape; decreasing with elasticity.

Table 10. Relationships between Technological Characteristics and Presence (Continued)

Factor	Conditions	Significant Effect	Presence Measure	Appendix A Reference
Dynamic shadows	Present, absent	Yes (present) ⁴	SUS Questionnaire	[Slater, 1995b]
	Present, absent	Yes (present) ⁵	Pointing to source	[Slater, 1995b]
	Real (FOV 48°× 36°), virtual (FOV 48° × 36°)	Yes (Virtual)	PQ Total, Interface Quality, Involved/Control, Resolution subscales	[Allen, 2001]
Environment type	Real, virtual, imagined	Yes (real) (2 items)	5 items on MCQ	[Hullfish, 1996]
	Real, HMD, 3D desktop, audio only	Yes (real)	SUS Questionnaire	[Mania, 2001]
	Real, desktop, audio only	Yes (real)	SUS Questionnaire	[Mania, 2000]
	Real, virtual	No	PQ Total	[Usoh, 2000]
	Real, virtual	Yes (real) (2 items)	6-item SUS Questionnaire	[Usoh, 2000]
	Real, Cave, desktop	Yes (Cave)	Wideström's questionnaire	[Wideström, 2000]
	Real, desktop	No	SUS Questionnaire	[Huie, 2003]
	Real, desktop	No	PQ	[Huie, 2003]
	Real normal, real horizontal 96° × 36°, real lower field 48° × 36°	Yes (normal)	PQ Total, Natural, Interface Quality, Resolution subscales	[Allen, 2001]
	90°, 50°, 10°	Yes (90°)	Hendrix's questionnaire	[Hendrix, 1996a (3)]
Frame rate	Unrestricted, 60°, 40°	Yes (unrestricted)	Prothero's questionnaire	[Prothero, 1995b]
	180°, 150°, 120°	Yes (180°)	8-item PQ	[Shim, 2001]
	48° × 36°, 36° × 27°, 24° × 18°	Yes (48° × 36°)	Magnitude estimation ratio-scale	[Snow, 1996 (1)]
	30, 20, 15, 10 fps	Yes (increasing with fps, except for 10 fps)	Aheart rate, Askin conductance, Askin temperature	[Meehan, 2001a (3)]
	30, 20, 15, 10 fps	Yes (except for 10 fps)	UCL Questionnaire	[Meehan, 2001a (3)]
	30, 20, 15, 10 fps	Yes (except for 10 fps)	Fear response	[Meehan, 2001a (3)]
Haptic cues	Mixed reality with real objects, virtual objects	Yes (mixed reality)	Hoffman's questionnaire	[Hoffman, 1996]
	Mixed reality maze, virtual maze	No	PQ	[Insko, 2001 (2)]
	VE with real objects, VE with virtual objects	No	Expanded SUS Questionnaire	[Lok, 2003]
	Mixed reality wooden ledge, virtual ledge	Yes (mixed reality)	Aheart rate, Askin conductance	[Meehan, 2001a (2)]
	Mixed reality wooden ledge, virtual ledge	No	Askin temperature	[Meehan, 2001a (2)]
	Mixed reality wooden ledge, virtual ledge	No	UCL Questionnaire (Presence)	[Meehan, 2001a (2)]
	Mixed reality wooden ledge, virtual ledge	No	UCL Questionnaire (Presence)	[Meehan, 2001a (2)]

⁴ For participants dominant in the visual sense.

Table 10. Relationships between Technological Characteristics and Presence (Continued)

Factor	Conditions	Significant Effect	Presence Measure	Appendix A Reference
Haptic force feedback	Mixed reality wooden ledge, virtual ledge	Yes (mixed reality)	UCL Questionnaire (Behavioral)	[Meehan, 2001a (2)]
	Mixed reality wooden ledge, virtual ledge	Yes (mixed reality)	Fear response	[Meehan, 2001a (2)]
	Present, absent	Yes (present)	PQ	[Sallnäs, 1999]
	Present, absent	No	PQ	[Bailey, 1994 (2)]
	Present, absent	Yes (present) (1 item)	Bystrom's questionnaire	[Bystrom, 1999]
	Present, absent	Yes (present)	Hendrix's questionnaire	[Hendrix, 1996a (1)]
Interaction (level of)	Present, absent	Yes (present)	PQ Total and all subscales	[Singer, 1995]
	Present, absent	Yes (present)	Magnitude estimation ratio-scale	[Snow, 1996 (2)]
	18, 12, 6 possible interactions	Yes (increasing interactions)	Magnitude estimation ratio-scale	[Snow, 1996 (3)]
	Driver, passenger	Yes (driver)	Paired comparison	[Welch, 1996 (1)]
	Low (~50 ms), high (~90 ms)	No	UCL Questionnaire	[Meehan, 2003]
	Low (~50 ms), high (~90 ms)	Yes (low)	Aheart rate	[Meehan, 2003]
Latency	Low (~50 ms), high (~90 ms)	No	Askin conductance	[Meehan, 2003]
	No additional delay, additional 1.5 sec. delay	Yes (no additional delay)	Paired comparison	[Welch, 1996 (2)]
	SGI workstation with high-level HMD, 3D joystick; Pentium II with medium level HMD, 2D mouse	No	Reality Judgment and Presence Questionnaire	[Botella, 1999]
	SGI workstation with high-level HMD, 3D joystick; Pentium II with medium level HMD, 2D mouse	No	Reality Judgment and Presence Questionnaire	[Botella, 1999]
	Hi-VE with head tracking & treadmill, Low-VE with no head tracking & joystick, standard map training	No	PQ Total and all subscales	[Singer, 1997]
	Seated with chin rest, seated w/o chin rest, standing	Yes (seated with chin rest) ⁵	11-item Bystrom questionnaire	[Bystrom, 1996]
Movement	Self-movement, preset	Yes (self movement)	IPQ	[Schubert, 2000 (1)]
	Reaching to touch object, mouse click	Yes (reaching)	Breaks in Presence	[Slater, 2000a]
	Head yaw	Yes (increasing with yaw)	SUS Questionnaire	[Slater, 1998]
	Bending	Yes (decreasing bending)	SUS Questionnaire	[Slater, 1998]
	3DOF joystick, 3DOF SpaceBall	No	Barfield's questionnaire	[Barfield, 1998]
	Movement & navigation, movement, navigation, none	No	Bystrom's questionnaire	[Bystrom, 1999]
Navigation	Fixed navigation, no movement	Yes (fixed)	Cho's questionnaire	[Cho, 2003]
	Walking in place, 3D mouse	Yes (walking in place) ⁶	3-item SUS Questionnaire	[Slater, 1995a]

⁵ Only for realism for participants seated without a chin rest.

Table 10. Relationships between Technological Characteristics and Presence (Continued)

Factor	Conditions	Significant Effect	Presence Measure	Appendix A Reference
Olfactory cues	Real walking, walking in place, push-button-fly	Yes (real walking)	Extended SUS Questionnaire	[Usuh, 1999]
	Real walking, walking in place, push-button-fly	No	Observed walking behavior	[Usuh, 1999]
	Treadmill, joystick, passive teleoperation	Yes (treadmill)	PQ	[Witmer, 1998 (2)]
	Present, absent	No	Dinh's questionnaire	[Dinh, 1999]
Presence manipulation	Biting candy bar, imagining biting candy bar	Yes (biting)	Hoffman's questionnaire	[Hoffman, 1999b]
	High presence, low presence	No	PQ	[Casaneva, 2001 (2)]
	Chess board in garden setting, chess board in void	No	3-item SUS Questionnaire	[Slater, 1996a]
	Gravity	No	3-item SUS Questionnaire	[Slater, 1994b]
Self-representation	Visual cliff	No	3-item SUS Questionnaire	[Slater, 1994b]
	Virtual body, virtual hand	Yes (hand)	PQ Natural subscale	[Allen, 2001]
	Visually faithful, generic	No	Expanded SUS	[Lok, 2003]
	Virtual body, pointer	No	PQ	[Singer, 1998]
Social presence	Virtual body, arrow cursor	Yes (body)	6-item SUS Questionnaire	[Slater, 1993a]
	High social presence, low social presence	No	Psotka's questionnaire	[Thie, 1998]
	High social presence, low social presence	Yes (high social pressure)	Come-back rate	[Thie, 1998]
	High social presence, low social presence	No	Extremity of decision made	[Thie, 1998]
Stacking depth	Transported through VEs via HMDs, doors	Yes (via HMD) Yes (through doors)	3-item SUS Questionnaire	[Slater, 1994b]
Stereopsis	Present, absent	Yes (present)	Cho's questionnaire	[Cho, 2003]
	Present, absent	Yes (present)	Hendrix's questionnaire	[Hendrix, 1996a (2)]
	Present, absent	Yes (interaction with head tracking)	PQ	[Singer, 1995]
Tactile cues	Present, absent	Yes (present)	Magnitude estimation ratio-scale	[Snow, 1996 (2)]
	Present, absent	Yes (present)	Dinh's questionnaire	[Dinh, 1999]
	Present, absent	Yes (present)	Cho's questionnaire	[Cho, 2003]
	Present, absent	Positive Yes (present)	Magnitude estimation ratio-scale	[Snow, 1996 (2)]
	Combinations high/low texture resolution/lighting quality, black/white grid texture	No	SUS Questionnaire	[Zimmons, 2003]
	Combinations high/low texture resolution/lighting quality, black/white grid texture	No	Aheart rate, Askin conductance	[Zimmons, 2003]

⁶ For participants who had a strong association with their virtual body.

Table 10. Relationships between Technological Characteristics and Presence (Continued)

Factor	Conditions	Significant Effect	Presence Measure	Appendix A Reference
Update rate	20, 15, 10Hz	Yes (increasing with Hz)	Barfield's questionnaire	[Barfield, 1998]
	25, 20, 15, 10, 5Hz	Yes (increasing with Hz)	13-item Barfield's questionnaire	[Barfield, 1995]
	16, 12, 8Hz	Yes (increasing with Hz)	Magnitude estimation ratio-scale	[Snow, 1996 (1)]
Visual display	5-wall Cave, monitor	Yes (Cave)	3-item Axelsson's questionnaire	[Axelsson, 2001]
	5-wall Cave, monitor	Yes (Cave)	2-item Axelsson's questionnaire	[Axelsson, 1999]
	4-wall Cave, HMD, monitor with shutter glasses	Yes (Cave)	Deisinger's questionnaire	[Deisinger, 2001]
	3-screen semi-circular mini-Cave, HMD, monitor	No	Engagement score, VE quiz	[Lawson, 1998]
	3-screen semi-circular mini-Cave, HMD, monitor	Yes (Cave)	RE quiz	[Lawson, 1998]
	HMD, monitor	Yes (HMD)	Startle response	[Nichols, 2000 (1)]
	HMD, monitor	No	Background awareness	[Nichols, 2000 (1)]
	HMD, monitor	Yes (HMD) (2 items)	Nichols' questionnaire	[Nichols, 2000 (1)]
	HMD, projection screen, monitor	Yes (monitor)	PQ	[Riley, 1999]
	5-wall Cave, 4-wall Cave, monitor	Yes (Cave)	Axelsson's object presence, place presence subscales	[Schroeder, 2001]
	Immersed with partner immersed, using monitor	Yes (both immersed)	Axelsson's place presence subscale	[Schroeder, 2001]
	HMD, monitor	No	2-item SUS questionnaire	[Slater, 2000b]
	HMD, monitor	No	4-item SUS questionnaire	[Slater, 1999]
Visual scene	HMD, monitor	Yes (HMD)	3-item SUS questionnaire	[Slater, 1996a]
	HMD, monitor	No	SUS Questionnaire	[Slater, 1995c]
	HMD, monitor	No	SUS Questionnaire	[Steed, 1999]
	HMD, 3D monitor	Yes (HMD)	Askin resistance	[Wiederhold, 1998]
	HMD, 3D monitor	No	Aheart rate, Askin temperature, Arespiration rate	[Wiederhold, 1998]
	Projection screen, monitor	No	PQ, SUS Questionnaire	[Youngblut, 2003]
	HMD, monitor	Yes (HMD)	PQ Interface subscale	[Youngblut, 2002]
	HMD, monitor	No	SUS Questionnaire	[Youngblut, 2002]
	As foreground, background	Yes (background)	Prothero's questionnaire	[Prothero, 1995a (1)]
	As foreground, background	Yes (background)	Prothero's questionnaire	[Prothero, 1995a (2)]

experienced. Used less frequently than questionnaires, psychological, physiological, and observed reaction presence measures all gave mixed results for this characteristic. Another characteristic for which a relatively large number of findings is available is the use of audio cues. In this case, nine of twelve findings indicated that use of audio cues increased a participant's sense of presence where, again, several different types of presence measures were used.

Consistent results across different studies were found for a few characteristics; specifically, the FOV, use of stereopsis, and update rate. All these characteristics had a significant positive effect on presence in all the studies conducted. Additional consistent findings were found within a single study using different types of presence measures for the use of dynamic shadows and frame rate, both showing a significant positive effect on presence. The majority of findings were positive for a significant relationship with head tracking, navigation, and participant movement. So, for this set of characteristics, the overall evidence seems to indicate that they deserve special consideration during the development of a VE application. A consistent lack of effect across studies is reported for level of equipment and scene realism.

Although inconsistent results across two or more studies were found for the use of color, level of detail, latency, level of interaction, olfactory cues, and texture mapping, the difference in actual conditions examined preclude comparison across studies. In some cases, inconsistent results were to be expected. For example, in the case of latency, Meehan (2003) found a lack of a significant relationship using the UCL Questionnaire and physiological presence measures, while Welch (1996) found a positive relationship. The latency introduced by Welch, however, was orders of magnitude greater than Meehan's. Thus, the difference between these findings seems reasonable. In other cases, the inconsistency of findings might be a result of the different type of presence measure used. More unexpected were the inconsistent findings for self-representation in a VE. In this case, we expected that a more complete self-representation would lead to an increased sense of presence, but this was supported by only one of four findings.

Results for some additional technological characteristics deserve special mention because they may indicate questionable validity of the type of presence measure used, or at least the difficulty in reaching conclusions about the role of a particular technological characteristic. In the case of environment type, for example, we would expect that participants would experience more presence in a real world environment than its virtual counterpart. Table 10, however, shows that Wideström et al. (2000) and Allen and Singer (2001) found that participants reported more presence in the VE than the real world environment the virtual world was modeled upon. That choice of which particular presence questionnaire is used has an impact on results was demonstrated by Usoh et al. (2000) who found a significant positive effect for type of environment using the SUS Questionnaire that was not present for the Witmer-Singer PQ. The inconsistent results for haptic cues and manipulation of social presence may be additional examples of the effect of different types of presence measures.

Examined in only a single study, the significant positive effects found for each of display resolution, haptic force feedback, and tactile cues were expected. The lack of relationship for avatar realism and presence manipulation is more unexpected, as are the mixed results for stacking depth.

Although the above give some indications about pertinent technological characteristics, additional controlled experimental studies are needed to see if results are repeatable. The next priority is to examine the role of specific characteristic across different types of realistic tasks, and across different types of VE interfaces. Of course, there remains a lack of data about possible interactions among characteristics (task and personal, as well as technological).

The next table, Table 11, is concerned with whether technological characteristics impact the sense of co-presence in a VE. Here, fewer characteristics have been examined, less than a quarter of those examined for (place) presence. The most commonly examined characteristic is, again, visual display type. The findings, in this case, are surprising in that four of six findings revealed no significant effect of visual display type on a participant's sense of co-presence, even comparing 5-wall Caves and desktop monitor displays, which represent the extreme ends of the immersive spectrum of current display types. The study conducted by Schroeder et al. (2001) did show the expected positive relationship, in that individuals reported more co-presence for the most immersive type of display device, in this case a 5-wall Cave. Even so, no significant difference was found between the use of a 4-wall Cave and a desktop monitor. Thus, from one perspective at least, the influence of display type seems less important for co-presence than (place) presence. However, Schroeder and his colleagues also compared conditions where one participant used a 5-wall Cave and his partner used either a second Cave system or a desktop monitor. In this case, a significant positive effect on co-presence was found only when both participants used the highly immersive Cave displays.

Casanueva (2001) looked for a relationship between co-presence and each of avatar realism and avatar functionality. In both cases, a significant positive effect on co-presence was found for increased avatar sophistication. As with (place) presence, the findings for type of environment were again surprising, with a single study reporting no differences among a real world environment, multi-screen Cave, or desktop monitor presentations of a virtual world. Findings for haptic force feedback and the manipulation of presence itself both gave the expected positive significant effect on co-presence, although each of these was examined in only a single study.

The lack of research in this area is surprising, given the expected wide use of collaborative VEs. One of the problems is that current presence measures are intended to assess the presence experienced by an individual. This requires identifying performance measures that relate to individual team performance in a meaningful manner. Another problem is the increased number of subjects needed to generate statistically valid data. When team-oriented performance measures are used, not only are more participants needed to form the teams, but the inevitable variation among participants across teams is difficult to control.

The final table in this section, Table 12, covers studies that addressed social presence. Only three technological characteristics have been examined for their effect on social presence. As for co-presence, this provides little information regarding the importance of particular characteristics or the validity of the measures used. While the majority of findings for co-presence did show a significant effect for the technological characteristics examined on co-presence, here three of the four findings showed no relationship. The one significant relationship, a positive effect, occurred when avatar gaze behavior was manipulated, although this relationship was found only for female participants. Further, it is interesting to note that Thie and van Wijk (1998) found no significant effect on their social presence measure when comparing one VE designed to promote a high level of social presence and another designed to minimize social presence. This lack of effect may have several causes and it would be useful to know, for example, whether the two VEs actually differed in the sense of social presence they evoked, or whether the questionnaire used was unable to distinguish any effect.

Table 11. Relationships between Technological Characteristics and Co-Presence

Factor	Description	Significant Effect	Co-Presence Measure	Appendix A Reference
Avatar functionality	Gestures & facial expressions, gestures, none	Yes (G&F)	Casanueva's questionnaire	[Casanueva 2001 (4)]
Avatar realism	Realistic human-like, cartoon-like, unrealistic	Yes (realistic)	Casanueva's questionnaire	[Casanueva 2001 (3)]
Collaboration	Pair, individual	Yes (pair)	Romano's questionnaire	[Romano 1998]
Environment type	Real, Cave, monitor	No	Widström's questionnaire	[Widström 2000]
Haptic force feedback	Present, absent	Yes (present)	Basdogan's questionnaire	[Basdogan 2000]
Presence manipulation	High presence, low presence	Yes (high presence)	Casanueva's questionnaire	[Casanueva 2001 (2)]
Visual display	5-wall Cave, monitor	No	Axelsson's questionnaire	[Axelsson 2001]
	5-wall Cave, monitor	No	Axelsson's questionnaire	[Axelsson 1999]
	5-wall Cave, 4-wall Cave, monitor	Yes (5-wall Cave)	Schroeder's questionnaire	[Schroeder 2001]
	Immersed with partner immersed, using monitor	Yes (immersed)	Schroeder's questionnaire	[Schroeder 2001]
	HMD, monitor	No	Slater's questionnaire	[Slater 2000b]
	HMD, monitor	No	Steed's questionnaire	[Steed 1999]

Table 12. Relationships between Technological Characteristics and Social Presence

Factor	Description	Significant Effect	Social Presence Measure	Appendix A Reference
Agent realism	Facial model (photographic texturing, flat-shaded)	No	Bailenson's questionnaire	[Bailenson 2001]
	Gaze behavior (5 levels realism)	Yes (females only)	Bailenson's questionnaire	[Bailenson 2001]
Haptic force feedback	Present, absent	No	Sallnäs's questionnaire	[Sallnäs 1999]
Social presence manipulation	High social presence, low social presence	No	Psotha's questionnaire	[Thie 1998]

3.2 Task Characteristics

Task characteristics, in the sense used here, do not relate to the activities performed in a VE. Instead, they pertain to the *manner* in which a participant is asked to complete a task, for example, whether collaboration with a partner is required or not, the type of instructional technique employed, or whether a participant has multiple exposures to a VE. At first glance, some of these characteristics seem to be the same as those identified as technological characteristics. There is a difference. In this case, *audio cues*, for example, refers to effect of providing different types of task-related information using audio cues, as opposed to the impact on presence of simply adding background sounds. Table 13 identifies the relevant experimental studies and their findings.

Findings about the potential relationship between multiple exposures and presence are the most frequent, but mixed. Commarford, Singer, and King (2001) found that increasing exposures to a VE during training (across a range from one to four exposures) had a significant positive effect on presence, as measured using the Witmer-Singer PQ. This relationship did not hold, however, when participants then performed their first mission in the VE, but reoccurred when comparing presence between the first and final missions. When looking for a relationship between a larger number of exposures (2 to 12), using physiological, observed reaction measures and the UCL questionnaire, Meehan (2001a) found results ranging from a positive to a negative effect. When looking at only one or two exposures, Meehan again found mixed correlations, and using three different types of presence measures. Although these inconsistencies may be attributable to the different presence measures used, they are particularly troubling because knowing whether the sense of presence increases or decreases across multiple exposures is crucial in determining the importance of the presence construct. Singer et al. (1997) did find a significant positive correlation between the time participants spent in a VE and Witmer-Singer PQ scores. More insight into possible relationships among the number of exposures, length of exposure, and time between exposures is needed.

There are nine other cases where a particular type of task characteristic has been examined in more than one study. For training type, even though the three studies involved used very different types of training, the findings showed a consistent lack of a significant effect on presence, and one of the studies showed this consistency for both the SUS Questionnaire and Witmer-Singer PQ. Findings for the relationship of virtual agents were relatively consistent, despite the differing sophistication of agent representation used. Two studies found no relationship with presence, while the third found a significant positive effect, but for only one subscale of the IPQ questionnaire. There are three studies that have looked for a significant effect of collaboration on presence. Two of these, see Casanueva (2001) and Romano, Brna, and Self (1998) did find a positive correlation. Bystrom and Barfield (1999) report no such effect, but without more details on the extent to which participants actually collaborated on the experiment task, it is uncertain whether this finding is, indeed, inconsistent with the others (all three studies used different presence questionnaires). The difference in findings for the three studies that examined the effect of the level of participant interaction in a virtual world may be due to the different types of presence measures used. Larsson, Västfjäll, and Kleiner (2001) and Welch et al. (1996) found the expected positive effect using two different presence questionnaires; Preston (1998) found no relationship but this was with a physiological presence measure (Δ heart rate). Task complexity, a potentially very important factor for the design of VE applications, has been examined in only two studies, both of which found a significant negative effect on presence, although it appears that gender has some influence here. The final task characteristic examined in more than one

Table 13. Relationships Between Task Characteristics and Presence

Factor	Description	Significant Relationship ⁷	Presence Measure	Appendix A Reference
Agents	Present, absent	No	IPQ	[Schubert, 2000 (1)]
	Present, absent	No	3-item SUS Questionnaire	[Usoh, 1996]
	Interaction expected, not expected	Yes (interaction expected)	IPQ	[Schubert, 2000 (2)]
Audio cues	Semantic & spatial, semantic, spatial, none	No	Spatial comprehension score	[Darken, 1999 (2)]
	Semantic & spatial, semantic, spatial, none	Yes (semantic & spatial, and semantic)	PQ	[Darken, 1999 (2)]
Collaboration	Pair, single user	No	Bystrom's questionnaire	[Bystrom, 1999]
	Required for task performance, not required	Yes (required)	SUS Questionnaire	[Casanueva, 2001 (1)]
	Pair, individual	Yes (pair)	Romano's questionnaire	[Romano, 1998]
Detail (level of)	Hanchev Army Heliport, portion of Arizona	No	PQ	[Johnson, 1995]
Directions	Attend to RE & VE, VE only	Yes (RE & VE)	Engagement, RE quiz	[Lawson, 1998]
	Attend to RE & VE, VE only	No	VE quiz	[Lawson, 1998]
Distance cues	Auditory tone every 10 feet, none	No	PQ	[Witmer, 1998 (2)]
Elapsed time to testing	Same day visit to real environment, 24 hours later	No	SUS Questionnaire	[Slater, 1995c]
Interaction (level of)	Actor, observer	Yes (actor)	SVUP	[Larsson, 2001]
	Interaction with VE, watching video with HMD	No	Aheart rate	[Preston, 1998]
	Car driver, passenger	Yes (driver)	Paired comparison	[Welch, 1996 (1)]
Meaning	Meaningful chess positions, meaningless	Yes (meaningful position) ⁸	Hoffman's questionnaire	[Hoffman, 1998]
Multiple exposures	After final training, simple movement training	Yes (final)	PQ Total, Involved/Control, Natural, Auditory, Haptic subscales	[Commarford, 2001]
	After final training, after first mission	Yes (final)	PQ Total, Involved/Control subscale	[Commarford, 2001]
	After final mission, after first mission	Yes (final)	PQ Total, Involved/Control subscale	[Commarford, 2001]
	2 to 12	Yes (increasing with number) ⁹	Askin conductance	[Meehan, 2001a (1)]
	2 to 12	Yes (decreasing with number)	Askin temperature, UCL Questionnaire (presence)	[Meehan, 2001a (1)]

⁷ These relationships are significant differences, unless explicitly noted otherwise.

⁸ Tournament players only.

⁹ After first exposure only.

Table 13. Relationships Between Task Characteristics and Presence (Continued)

Factor	Description	Significant Relationship ⁷	Presence Measure	Appendix A Reference
2 to 12		No	UCL Questionnaire (behavior)	[Meehan, 2001a (1)]
2 to 12		Yes (decreasing with number)	Fear Response	[Meehan, 2001a (1)]
1 to 2		No correlation	Aheart rate, Askin conductance, Askin temperature, Fear Response	[Meehan, 2001a (2)]
1 to 2		Negative correlation	UCL Questionnaire	[Meehan, 2001a (2)]
1 to 2		Negative correlation ¹⁰	Askin conductance, Askin temperature, Fear Response	[Meehan, 2001a (3)]
1 to 2		Negative correlation ¹¹	Aheart rate, UCL Questionnaire (behavioral)	[Meehan, 2001a (3)]
1 to 2		No correlation	UCL Questionnaire (presence)	[Meehan, 2001a (3)]
1 to 2		Positive correlation	PQ	[Riley, 1999]
Personal risk (virtual)	Rear elevator doors missing, doors present	No	Magnitude estimation ratio-scale	[Snow, 1996 (2)]
Practice with interface	Extended (30 minutes), basic (2–3 minutes)	Yes (extended)	PQ Interface subscale	[Youngblut, 2002]
	Extended (30 minutes), basic (2–3 minutes)	No	SUS Questionnaire	[Youngblut, 2002]
Realism	Sense of loss of realism	Positive correlation	6-item SUS Questionnaire	[Slater, 1993a]
Second user	Present, absent	Yes (present)	Magnitude estimation ratio-scale	[Snow, 1996 (3)]
Task complexity	Count & remember location, simple count	Yes (simple count) ¹²	SUS Questionnaire	[Slater, 1998]
	Small number of mines, large number	Yes (large number)	PQ	[Riley, 2001]
Task expertise	Self-rating	Yes (increasing) ¹³	Hoffman's questionnaire	[Hoffman, 1998]
	Self-rating	No correlation	OPQ Total and all subscale	[Stevens, 2002]
Time spent in VE	Minutes	Positive correlation	PQ Total, Involved/Control subscale	[Singer, 1997]
Training type	Exploratory, restrictive	No	PQ	[Bailey, 1994 (2)]
	Extensive interaction, simple training	No	PQ, SUS Questionnaire	[Huie, 2003]
	Building, VE, symbolic (route learning)	No	PQ	[Witmer, 1994b (1)]

¹⁰ After first exposure only.

¹¹ Over exposures on the same day.

¹² For females only.

¹³ Significant interaction with meaningfulness such that participants with prior experience showed a positive effect of meaningfulness of presence.

study is prior task expertise. Here, again, there are only two studies to consider and these gave inconsistent results.

The use of audio cues, type of task directions, and practice with the VE interface were all examined in a single study using two different presence measures. In all these cases, the findings were mixed, implying that the presence measures were assessing different aspects of the presence construct. Examined in a single study using a single presence measure, the lack of a significant effect for each of the level of geographic complexity, distance cues, the elapsed time to testing, and personal risk, is perhaps unexpected but little more can be said without any type of corroborative data. The positive effects of each of meaningfulness and the presence of a second user on presence were more likely. Similarly, the positive correlation between the sense a loss of realism and the experience of presence.

Only two studies considered the relationship between task characteristics and co-presence, see Table 14. In both cases, collaboration and participant accord, positive relationships were found between the task characteristic in question and co-presence. It is interesting to note that, in his study, Casaneuva's (2001) finding was consistent with that for a relationship between collaboration and (place) presence, even though he found no significant correlation between (place) presence and co-presence themselves.

We are not aware of any studies that have examined relationships between task characteristics and social presence.

3.3 Personal Characteristics

Thirty-eight studies have examined the potential relationship between seventeen different personal characteristics and (place) presence. In very few cases were these examinations the main focus of a study; instead information on personal characteristics was collected as ancillary data. As shown in Table 15, the personal characteristics examined range from age to prior knowledge of VE technology.

The most examined personal characteristic is susceptibility to immersion, with all but one of twenty-nine findings using Witmer and Singer's Immersive Tendencies Questionnaire (ITQ) (Singer, 1997). The ITQ was developed to help in identifying behavioral characteristics likely to affect the extent of presence a participant is likely to experience in a VE. It comprises eighteen questions, using 7-point scales, anchored at the end-points with opposing descriptions and including a mid-point anchor. Based on data from three experiments, Singer and Witmer report a Cronbach's alpha of .81 for the ITQ reliability. Additionally, cluster analyses revealed three subscales: Involvement, Focus, and Games. The other measure of susceptibility to immersion was developed by Psotka (1996). Psotka performed a cluster analysis on this 12-item questionnaire and found four subscales: imagination, vividness of imagery and claustrophobia, self control, and the ability to do two things at a time. In a later study, Thie and van Wijk (1998) were unable to replicate Psotka's findings and report a relatively low alpha of .67 for the questionnaire.

As suggested above, the potential value of the ITQ, or any valid susceptibility measure, lies in its ability to determine which people are most likely to benefit from, or conversely, experience problems, in using a VE application. In examining relationships between presence and immersive tendencies, the most commonly used presence measure was the Witmer-Singer PQ (eighteen findings), followed by the SUS Questionnaire (six findings).

Table 14. Relationships between Task Characteristics and Co-Presence

Factor	Description	Significant Relationship	Co-Presence Measure	Appendix A Reference
Collaboration	Required, not required	Significant effect (required)	14-item Casanueva's questionnaire	[Casanueva, 2001 (1)]
Participant accord	7-item questionnaire	Positive correlation	6-item SUS Questionnaire	[Steed, 1999]

Table 15. Relationships between Person-Related Measures and Presence

Characteristic	Description	Significant Relationships ¹⁴	Presence Measure	Appendix A Reference
Age	Years	Negative (1 item)	3-item Barfield questionnaire	[Barfield, 1993 (1)]
	Years	None	11-item Bystrom questionnaire	[Bystrom, 1996]
	Years	None	OPQ Total and all subscale	[Stevens, 2002]
	Years	None	PQ, SUS Questionnaire	[Youngblut, 2002]
Adaptability	Self rating	Negative	SUS Questionnaire	[Slater, 1993a]
Belief simulation quality improved performance	11-item questionnaire	Positive	VRUSE questionnaire	[JSC, 2000]
Cognitive style	Creative Imagination Scale	Positive	Sas's questionnaire	[Sas, 2001]
	Tellegen Absorption Scale (TAS)	None	Sas's questionnaire	[Sas, 2001]
	Davis' Interpersonal Reactivity Index	Positive	Sas's questionnaire	[Sas, 2001]
	Myers-Briggs Type Indicator	None	Sas's questionnaire	[Sas, 2001]
	Hidden Figures Test	None	PQ	[Singer, 1995]
	NLP Representation	Positive for visual, kinesthetic Negative for auditory	3-item SUS Questionnaire	[Slater, 1994b]
	NLP Representation	Positive for visual and kinesthetic ¹⁵ Negative for auditory and kinesthetic ¹⁶	SUS Questionnaire	[Slater, 1993a]

¹⁴ These relationships are correlations unless explicitly noted as a significant difference.

¹⁵ If have virtual body as self-representation.

Table 15. Relationships between Person-Related Measures and Presence (Continued)

Characteristic	Description	Significant Relationships ¹⁴	Presence Measure	Appendix A Reference
Comfort (computers)	NLP Representation	Negative for auditory ¹⁷	3-item SUS Questionnaire	[Usoh, 1996]
	Dissociative Experience Scale (DES)	Positive	Wiederhold's questionnaire	[Wiederhold, 2001]
	Tellegen Absorption Scale (TAS)	Positive	Wiederhold's questionnaire	[Wiederhold, 2001]
	Self rating	Positive (1 item)	3-item Barfield questionnaire	[Barfield, 1993 (1)]
	Self rating	Positive (1 item)	3-item Barfield questionnaire	[Barfield, 1993 (1)]
Computer use	Self rating	Positive (1 item)	3-item Barfield questionnaire	[Barfield, 1993 (1)]
	Self-rating	None	PQ, SUS Questionnaire	[Huie, 2003]
	Self-rating	None	PQ	[Singer, 1997]
Education (level of)	Self-rating on ordinal scale	Negative	PQ Total and all subscales	[Youngblut, 2002]
	Self-rating on ordinal scale	None	SUS Questionnaire	[Youngblut, 2002]
Game playing	Self rating	Negative	PQ Interface subscale	[Huie, 2003]
	Self rating	None	SUS Questionnaire	[Huie, 2003]
	Self rating	None	SUS Questionnaire	[Mania, 2001]
	Self rating	Positive	Romano's questionnaire	[Romano, 1998]
	Self rating	None	PQ	[Singer, 1997]
	Self rating	Negative	Expanded SUS Questionnaire	[Usoh, 1999]
Video games	Self rating	None	Fear responses	[Usoh, 1999]
	Self rating	Negative	PQ Interface subscale	[Huie, 2003]
	Self rating	None	SUS Questionnaire	[Youngblut, 2003]
	Self rating	Positive	PQ Involved/Control subscale	[Youngblut, 2003]
	Self rating	Positive	PQ Involved/Control subscale	[Youngblut, 2002]
	Hours, transformed to ordinal scale	Negative	PQ Involved subscale, SUS	[Youngblut, 2002]
	Hours, transformed to ordinal scale	None	PQ Total and all subscales, SUS	[Youngblut, 2002]
	Male, female	No significant effect	PQ	[Insko, 2001 (2)]
	Male, female	Significant effect ¹⁸	Prothero's questionnaire	[Prothero, 1995b]
	Male, female	No significant effect	Sas's questionnaire	[Sas, 2001]
Gender	Male, female	No significant effect ¹⁹	SUS Questionnaire	[Slater, 1998]

¹⁶ If no virtual body as self-representation.

¹⁷ If VE unfamiliar.

¹⁸ No further analysis performed because of imperfect counterbalancing.

¹⁹ Significant interaction with task complexity with females in more complex task reported lower presence and males reporting more presence in the more complex task.

Table 15. Relationships between Person-Related Measures and Presence (Continued)

Characteristic	Description	Significant Relationships ¹⁴	Presence Measure	Appendix A Reference
Health	Male, female	None	OPQ Total or any subscale	[Stevens, 2002]
	Male, female	No significant effect	PQ	[Witmer, 1998 (2)]
	Male, female	No significant effect	PQ, SUS Questionnaire	[Youngblut, 2003]
	Male, female	None	PQ, SUS Questionnaire	[Youngblut, 2002]
	Male, female	No significant effect	SUS Questionnaire	[Zimmons, 2003]
Spatial awareness	Questionnaire	None	PQ	[Singer, 1997]
	Visualization, Ekstrom VZ-2 test	None	PQ, SUS Questionnaire	[Huie, 2003]
	Guilford-Zimmerman test	None	PQ	[Insko, 2001 (2)]
	Carter and Wolstad test	Positive	PQ	[Riley, 1999]
	Spatial Awareness Test	Negative (immersed) None (desktop)	Questionnaire with 3 presence items	[Slater, 1996a]
Susceptibility to immersion	Spatial orientation	None	PQ	[Insko, 2001 (2)]
	Spatial orientation, Ekstrom S-1 test	None	SUS Questionnaire	[Youngblut, 2003]
	Spatial orientation, Ekstrom S-1 test	Positive	PQ Total and all subscales	[Youngblut, 2003]
	Spatial orientation, Ekstrom S-2 test	None	PQ, SUS Questionnaire	[Youngblut, 2003]
	Spatial scanning, Ekstrom SS-3 test	None	PQ, SUS Questionnaire	[Youngblut, 2003]
	Visual memory, Ekstrom MV-2 test	None	PQ, SUS Questionnaire	[Youngblut, 2003]
	Visualization, Ekstrom VZ-2 test	None	PQ, SUS Questionnaire	[Youngblut, 2003]
	Visualization, Ekstrom VZ-2 test	None	PQ, SUS Questionnaire	[Youngblut, 2002]
	ITQ Focus subscale	Positive ²⁰	PQ Total, Involved/Control, Interface Quality subscales	[Allen, 2001]
	ITQ Games subscale	Positive	PQ Total, Involved/Control subscale	[Allen, 2001]
	ITQ	Positive	PQ	[Bailey, 1994 (2)]
	ITQ	Positive	SUS Questionnaire	[Casanueva, 2001 (1)]
	ITQ	Positive (high presence only)	PQ	[Casanueva, 2001 (2)]
	ITQ	Positive	SUS Questionnaire	[Casanueva, 2001 (3)]
	ITQ	Positive	SUS Questionnaire	[Casanueva, 2001 (4)]
ITQ	Positive after initial training		PQ Total, Involved, Resolution subscales	[Commarford, 2001]
	None after final training		PQ	[Commarford, 2001]

²⁰ For VE participants.

Table 15. Relationships between Person-Related Measures and Presence (Continued)

Characteristic	Description	Significant Relationships ¹⁴	Presence Measure	Appendix A Reference
	ITQ	None	PQ, SUS Questionnaire	[Huie, 2003]
	ITQ	None	PQ	[Knerr, 1994 (1)]
	ITQ	None	PQ	[Lampton, 2001]
	ITQ	None	VE quiz	[Lawson, 1998]
	ITQ	Positive	PQ	[Riley, 2001]
	ITQ	Positive	PQ	[Riley, 1999]
	ITQ Focus subscale	Positive	PQ Total, Involved, Natural subscales	[Singer, 1997]
	ITQ Involvement subscale	Negative	PQ Interface Quality subscale	[Singer, 1997]
	ITQ	Positive	PQ	[Singer, 1995]
	ITQ	None (for males)	OPQ	[Stevens, 2002]
		Negative (for females)	OPQ Natural subscale	
	ITQ Focus subscale	Positive (for males)	OPQ Total, Involved, Natural subscales	[Stevens, 2002]
	ITQ Involved subscale	Positive (for males)	OPQ Involved subscale	[Stevens, 2002]
		Negative (for females)	OPQ Involved subscale	
	ITQ Games subscale	None (for males)	OPQ Total and all subscales	[Stevens, 2002]
		Negative (for females)	OPQ Natural subscale	
	Psotka's 15-item Susceptibility for Presence questionnaire	None	Psotka's questionnaire	[Thie, 1998]
	ITQ	None	PQ	[Witmer, 1994a (1)]
	ITQ	None	PQ	[Witmer, 1994a (2)]
	ITQ	Positive	SUS Questionnaire	[Youngblut, 2003]
	ITQ	None	PQ	[Youngblut, 2003]
	ITQ Games subscale	Negative	PQ	[Youngblut, 2002]
	ITQ Focus subscale	Negative	SUS Questionnaire	[Youngblut, 2002]
	Direction sense	None	PQ	[Singer, 1997]
Task-related experience	Map confidence	Positive	PQ Interface Quality subscale	[Singer, 1997]
	Map memory	None	PQ	[Singer, 1997]
	Self-rating of chess experience	Positive	Questionnaire with 3 presence items	[Slater, 1996a]
	Chess expertise	None	4-item Hoffman's questionnaire	[Hoffman, 1998b]
	Self-rating (different type tool use)	None	PQ and all subscales, SUS	[Youngblut, 2002]
	Topographical map experience	None	PQ	[Singer, 1997]

Table 15. Relationships between Person-Related Measures and Presence (Continued)

Characteristic	Description	Significant Relationships ¹⁴	Presence Measure	Appendix A Reference
VE experience	Self-rating	None	PQ	[Singer, 1997]
	Self-rating	Negative	6-item SUS Questionnaire	[Uno, 1997]
	Self-rating	Positive	SUS Questionnaire	[Youngblut, 2003]
	Self-rating	None	PQ	[Youngblut, 2003]
	Self-rating	Negative	PQ Total, Involved subscale	[Youngblut, 2002]
	Self-rating	None	SUS Questionnaire	[Youngblut, 2002]
VE technology knowledge	Self-rating	Positive	SUS Questionnaire	[Youngblut, 2003]
	Self-rating	None	PQ	[Youngblut, 2003]
	Self-rating	Negative	PQ Total, Involved subscale	[Youngblut, 2002]
	Self-rating	None	SUS Questionnaire	[Youngblut, 2002]
	Self-rating	Negative	PQ Total, Involved subscale	[Youngblut, 2002]
	Self-rating	None	SUS Questionnaire	[Youngblut, 2002]

Results for the Witmer-Singer PQ were mixed, with nine significant positive correlations between the ITQ and presence, and one negative correlation. Similarly, for the SUS Questionnaire, four significant positive correlations between a susceptibility for immersion and presence were found, and one negative correlation. Overall, the majority of findings do show a significant positive relationship between a susceptibility to immersion and the experience of presence. Whether the inconsistency in the findings can be attributed to problems with immersive tendency measures, differences in the VE environments and tasks, etc. is uncertain. In particular, interaction with other personal characteristics, or some unknown factor, may be pertinent.

The findings for potential relationships between a participant's spatial awareness and presence are surprising. Since the presentation of virtual worlds is, currently, predominantly visual, we expected relationships between various cognitive functions, such as the ability to mentally transpose 3D shapes, and presence. However, out of eighteen findings, only three significant correlations were found, and only two of these were in the expected direction. Most of the spatial awareness characteristics were measured using Ekstrom et al. (1999) cognitive tests. Fourteen of the findings came from just three studies, see Huie, Youngblut, and Buck (2003), Youngblut and Huie (2003), and Youngblut and Perrin (2002). Among them, these studies examined relationships for two spatial orientation tests, one spatial scanning, and one visualization test, using both the SUS Questionnaire and Witmer-Singer PQ. Only one significant correlation was found, a positive correlation between Ekstrom's S-1 spatial orientation test and the PQ. One of the remaining three studies in this group found a positive correlation between the Carter and Wolstad (1985) test and the Witmer-Singer PQ, see Riley and Kaber (1999). Slater et al. (1996a) found an unexpected negative correlation using a different spatial awareness test, see Smith and Whetton (1988), when participants used an HMD, but no relationship for users of a desktop monitor. We are curious whether similar findings would occur using different presence measures.

Seven additional studies examined cognitive style, using tests such as the Tellegen Absorption Scale (TAS), see Tellegen and Atkinson (1974), and the Myers-Briggs Type Indicator, see (Myers and McCauly, 1998). The findings using different presence measures were mixed. Sas and O'Hare (2001) found no significant correlation between the TAS and presence, while Wiederhold et al. (2001) found a significant positive correlation. The only other cognitive style measure used across multiple studies is NLP representation, see (Slater, 1994b). It is assessed using a questionnaire that seeks to determine a person's primary representation system: visual, auditory, or kinesthetic. Here, three studies by Slater and his colleagues (Slater, 1994b, 1993a; Usuh, 1996) all used some variation of the SUS Questionnaire. They report consistent, significant negative correlations for people who were dominant in the auditory sense, although the existence of a significant positive correlation for those dominant in the visual and kinesthetic senses at times depended on whether a participant was represented by a virtual body in the virtual world. Overall, there were more significant correlations for this group of cognitive styles than was found for specific measures of spatial awareness, but the results were, again, mixed.

Two other personal characteristics have seen fairly extensive examinations; these are game playing and gender. The potential relationship between game playing and presence has been examined using three different presence questionnaires and one observed reaction measure. The fourteen findings based on presence questionnaires were mixed, some studies finding no relationship with presence and others finding either a significant positive or negative correlation. Usuh et al. (1999) found no relationship based on observed fear reactions. In all, from a total of fifteen findings, five negative correlations and three positive correlations were found. Thus, in approximately half the cases, game playing had no influence on presence in the majority of cases. Was this to be expected? We assumed that frequent use of computer and video games would

build familiarity with becoming involved in some type of virtual world, just as practice with typical VE manual interfaces such as joysticks would facilitate interacting with a virtual world. Overall, the findings do not support these assumptions.

In the majority of cases, the relationship between personal characteristics and presence has been examined by looking for statistically significant correlations between the two. This pattern changes in the case of gender. Here, most studies report on significant effects, that is, treating gender as an experimental factor. Nine of the studies used presence questionnaires, with four of the twelve findings relating to the SUS Questionnaire, and five to the Witmer-Singer PQ. In every case but one, where Prothero's questionnaire was used, no significant effect or significant correlation was found between gender and presence. These largely consistent findings are encouraging, indicating that, at least with respect to presence, VE applications are equally suited for males and females.

Table 15 provides findings for several other personal characteristics that have been examined across a number of studies. Findings from three studies that examined the potential relationship with comfort of computer use all showed a significant positive correlation with presence, although another two that considered frequency of computer use found a lack of a relationship. Three of four studies using various presence questionnaires found no significant correlation between age and presence. Findings for level of education, VE experience, and knowledge of VE technology were also mixed. The majority of findings for task-related experience showed no relationship with presence. These results are surprising but, due to the impact of the difference between the types of tasks examined, should be considered on an individual basis, rather than as a group.

Three other personal characteristics were examined in only a single study each. The significant negative relationship between adaptability and presence was unexpected, since it seems likely that a person who adapts easily to new situations would be likely to feel higher levels of presence. The positive relationship between a belief that simulation quality improves performance and presence is more understandable. The lack of a relationship between self-reported state of health and presence is perhaps surprising, but encouraging for the usability of VEs. Further investigation with respect to the occurrence of simulator sickness symptoms would be useful here.

Table 16, identifies five studies that have examined the potential relationship between personal characteristics and co-presence. As for (place) presence, susceptibility to immersion is the most commonly examined personal characteristic. All conducted in highly similar circumstances, a significant (positive) correlation was found in only one of four studies, and in that case only when the task performed by the participants required active collaboration. All other findings in this category come from a single study conducted by Basdogan et al. (2000). Here, a variety of personal characteristics were considered, ranging from age to social anxiety. All these characteristics had significant correlations with co-presence, both positive and negative. It is worth noting that age, computer use, and gender were examined for both (place) presence and co-presence, and the findings were different for the two types of presence.

Only one experimental study has examined the relationship between personal characteristics and social presence. This was a study conducted by Bailenson (2001) that found no relationship between gender and Bailenson's 5-item presence questionnaire.

Table 16. Relationships between Person-Related Measures and Co-Presence

Characteristic	Description	Significant Relationship ²¹	Co-Presence Measure	Appendix A Reference
Age	Years	Negative	Basdogan's questionnaire	[Basdogan, 2000]
Computer use	Self-rating	Positive	Basdogan's questionnaire	[Basdogan, 2000]
Gender	Male, female	Significant effect (female)	Basdogan's questionnaire	[Basdogan, 2000]
Social anxiety	Social Anxiety Test	Negative (males), Positive (females)	Basdogan's questionnaire	[Basdogan, 2000]
Social anxiety of partner	Social Anxiety Test	Positive	Basdogan's questionnaire	[Basdogan, 2000]
Susceptibility to immersion	ITQ	Positive (when task collaboration required)	Casanueva's questionnaire	[Casanueva, 2001 (1)]
	ITQ	None	Casanueva's questionnaire	[Casanueva, 2001 (2)]
	ITQ	None	Casanueva's questionnaire	[Casanueva, 2001 (3)]
	ITQ	None	Casanueva's questionnaire	[Casanueva, 2001 (4)]

²¹ These relationships are correlations, unless explicitly noted as effects.

4. Studies Examining the Potential Relationship Between Presence and Performance

In practical terms for military VE applications, presence is only important with respect to its impact on task performance. Yet, of the 103 experiments summarized in Appendix A, only 22% have considered the existence of a relationship between presence and some direct measure of task performance. At first glance, this might seem like a large enough number of studies to provide some conclusive findings. Unfortunately, the wide range of types of VE interfaces, tasks, and presence measures that have been studied preclude most forms of statistical analysis across studies. An additional 20% of the studies have reported on relationships with other task-related outcomes that might provide further insight into the role of presence. These indirect outcomes range from self-reported ratings of collaboration on a task performed with other VE participants to the experience of simulator sickness symptoms. (Some studies reported on both direct and less-direct measures of task performance.)

This section starts with identifying studies that have reported on direct task performance measures. This is followed by identification of studies that have reported on relationships between presence and more indirect task-related measures. It concludes with a discussion on the crucial question: Are relationships between presence and task performance likely to be causal, that is, will manipulating the sense of presence in a VE result in improved task performance?

In the following, the majority of the data relate to (place) presence. Relatively few researchers have examined relationships with co-presence and there are no reported studies that discuss relationships between social presence and task performance.

4.1 Relationship with Task Performance

As previously mentioned, much of the existing research has been conducted using “toy” tasks that are not reflective of expected military applications. This is typical for initial research into human factors and many other issues. Moreover, the majority of the findings identified here relate to part-tasks, or elements of a task, such as the ability to move objects between different bins, and the time taken for choice reaction tasks. Additional research along the same lines may still be needed to answer particular questions about the presence construct. After a decade of research, however, we would like some indications of whether presence is important with respect to task performance for anticipated military applications.

Accordingly, considering first (place) presence, we start with the fifteen studies that looked at presence and task performance on complete tasks. These studies are identified in Table 17. As the table shows, the number of measures of task performance examined to date is relatively small and can be easily grouped as relating to the accuracy of task performance, acquisition of various types of knowledge, and time to complete the task. An important point to note is that nine of these studies examined task performance in a VE, only five examined transfer of training to real world activities.

Table 17. Relationships between General Performance Measures and Presence

Measure	Description	Significant Correlation	Presence Measure	Appendix A Reference
Accuracy	Number of correct chess moves repeated	None	3-item SUS Questionnaire	[Slater, 1996a]
	Count of errors made performing trained task	None	PQ, SUS Questionnaire	[Huie, 2003]
	Count of errors made performing trained task	Negative	PQ Involved/Control subscale, SUS	[Youngblut, 2002]
	Summed score across mission procedures	Positive	SUS Questionnaire	[Youngblut, 2003]
	Summed score across mission procedures	None	PQ	[Youngblut, 2003]
Configuration knowledge	Paper projective convergence test	Positive	PQ	[Bailey, 1994 (2)]
	Computer projective convergence test	None	PQ	[Bailey, 1994 (2)]
	Paper projective convergence test	Positive	PQ	[Witmer, 1996 (1)]
Knowledge acquisition	Questionnaire on task procedures	Negative	SUS Questionnaire	[Huie, 2003]
	Questionnaire on task procedures	Positive	PQ Interface subscale	[Huie, 2003]
	16-item knowledge acquisition questionnaire	None	SUS Questionnaire	[Mania, 2000]
	Questionnaire on task procedures	None	PQ, SUS Questionnaire	[Youngblut, 2002]
Memory recall	Memory recall and spatial awareness questionnaire	None	SUS Questionnaire	[Mania, 2001]
Route knowledge	Photograph ordering test	Positive	PQ	[Bailey, 1994 (2)]
	Time taken, count of attempted wrong turns, distance traveled, count of collisions	None	PQ	[Bailey, 1994 (2)]
	Number of wrong turns, route traversal time, misidentified destinations, distance traveled	None	PQ	[Witmer, 1996 (1)]
Spatial knowledge	Map building, pointing scores, landmarks identified	None	PQ	[Darken, 1999 (2)]
	Accuracy of pointing, averaged over landmarks	Positive	PQ Involved/Control, Naturalness	[Singer, 1997]
	Projective convergence accuracy and consistency	Negative	PQ Interface Quality subscale	[Singer, 1997]
Time to complete	Time to complete search task	Positive ²²	11-item Bystrom questionnaire	[Bystrom, 1996]
	Time to complete trained task	None	SUS Questionnaire	[Huie, 2003]
	Time to complete trained task	Negative	PQ Total	[Huie, 2003]
	Avg. time to mine-neutralization	Negative	PQ	[Riley, 2001]
	Time to navigate telerobotic vehicle	Negative (map users)	PQ	[Riley, 1999]
	Ratio of time in real world to time in VE	Negative ²³	SUS Questionnaire	[Slater, 1995c]
	Time to complete search task	None	PQ, SUS Questionnaire	[Usoh, 2000]
	Time to complete trained task	None	PQ, SUS Questionnaire	[Youngblut, 2002]

²² For participants who reported their sense of presence increased when they were seated, as opposed to standing.

²³ For participants dominant in the auditory sense.

What conclusions can be drawn from the available data? In terms of overall numbers, there are thirty-two findings (the number of performance measures multiplied by presence measures counted across studies). Fourteen (34%) of these showed a significant correlation between the performance measure and presence, all but three in the expected direction. But data for each of the categories of task performance given in Table 17 are mixed. Some of the studies indicate specific problems with various measures. The findings of one study by Bailey and Witmer (1994a), for example, reveals sensitivity to the form of task performance measure used. In this case, different forms of a projective convergence test (pencil-and-paper and computer-based) as a measure of configuration knowledge gave different results. Looking at the findings for studies that examined route knowledge shows extreme sensitivity to the type of task performance measure used. Of course, the type of presence measurement also plays an important role. Here, again, there are inconsistencies that complicate forming any general conclusions. For example, in the four studies that used both the SUS Questionnaire and Witmer-Singer PQ, only half of the (six) findings gave consistent results across these two presence questionnaires.

A final point to note is that little consideration has been paid to the role that possible interactions with technical, task, and personal characteristics might play in any relationship between presence and task performance.

An additional set of studies examined the relationship between presence and task performance for a total of fourteen part-tasks that are collectively known as the Virtual Environment Performance Assessment Battery (VEPAB) tasks, developed by the U.S. Army Research Institute for the Behavioral and Social Sciences, see Singer et al. (1995). The results are given in Table 18. Here, the different types of performance measures used are grouped into measures related to accuracy, the number of collisions made in a virtual world, the number of errors made, and the time taken to complete a task. The Witmer-Singer PQ and Snow's (1996) magnitude estimate ratio-scale were the only presence measures used. There are six studies to consider, all conducted between 1994 and 1996. From this small number of studies, there are a total of 50 findings to review. Half of these showed significant correlations between a task performance measure and presence, and over 90% of these correlations were in the expected direction. Since 46% of all the findings were related to the Bins and Choice Reaction tasks, it is worthwhile looking at these particular tasks more closely. Of the thirteen findings for the Bins task, slightly over half gave a significant correlation with presence, all indicating that task performance increased with the sense of presence. For the Choice Reaction task, however, only one of the ten findings showed a significant correlation with presence. The time to complete the task decreased significantly as the sense of presence increased.

Looking at these data from a different point of view, that of types of performance measures, the findings for task accuracy were most mixed, with six positive and two negative correlations out of a total fourteen findings. The results for the number of errors made is more encouraging, with four out of five findings indicated a significant negative correlation. The majority of the data relate to the time taken to complete a task. In this case, fourteen of the thirty-one results (45%) showed a significant correlation, all negative.

To summarize, of the eighty-two findings given in Table 17 and Table 18, nearly 50% showed a significant correlation between presence and task performance, and this correlation was in the desired directions for all but three findings. This figure may appear encouraging, but many unknowns remain. For example, the number of positive findings may increase or decrease with use of different presence measures, or forms of performance measures.

Table 18. Relationships between VEPAB Performance Measures and Presence

Measure	Description	Significant Correlation	Presence Measure	Appendix A Reference
Accuracy	% total trial time cursor kept on target, time to 1 st intercept in fixed tracking task	None	PQ	[Singer, 1995]
	% total trial time cursor kept on target, time to 1 st intercept in moving tracking task	None	PQ	[Singer, 1995]
# Collisions	Bins task	None	PQ	[Singer, 1995]
	Bins task	Positive	PQ Total, Control Responsiveness/Distracton, Involvement, Sensory Exploration subscales	[Witmer, 1994a (1)]
	Bins task	Positive	PQ Involvement subscale	[Witmer, 1994a (2)]
	Dial task	Positive	PQ Control Responsiveness, Involvement subscales	[Witmer, 1994a (1)]
	Dial task	Positive	PQ Involvement, Sensory Exploration subscales	[Witmer, 1994a (2)]
	Distance estimation task	None	PQ	[Singer, 1995]
	Flying-thru-Windows task	Negative	PQ Total, Control Responsiveness/Distracton, Interface Awareness subscales	[Witmer, 1994a (1)]
	Flying-thru-Windows task	Negative	PQ Total, Control Responsiveness subscale	[Witmer, 1994a (2)]
	Slide task	Positive	PQ Total, Involvement, Control Responsiveness, Sensory Exploration subscales	[Witmer, 1994a (1)]
	Slide task	Positive	PQ Total, Control Responsiveness, Sensory Exploration subscales	[Witmer, 1994a (2)]
	Reaction (choice) task	None	PQ	[Witmer, 1994a (1)]
	Reaction (choice) task	None	PQ	[Witmer, 1994a (2)]
	Doorways task	None	PQ	[Singer, 1995]
	Bins task	None	PQ	[Singer, 1995]
# Errors made	Bins task	Negative	PQ	[Snow, 1996 (1)]
	Bins task	Negative	PQ	[Snow, 1996 (2)]
	Bins task	Negative	PQ	[Snow, 1996 (3)]
	Bins task	None	PQ	[Singer, 1995]
	Bins task	None	PQ	[Snow, 1996 (1)]
	Bins task	None	PQ	[Snow, 1996 (2)]
	Bins task	Negative	PQ	[Snow, 1996 (3)]
	Bins task	Negative	PQ Total, Involvement, Control Responsiveness/Distracton subscales	[Witmer, 1994a (1)]
	Bins task	None	PQ	[Witmer, 1994a (2)]
	Bins task	None	PQ	[Witmer, 1994a (2)]

Table 18. Relationships between VEPAB Performance Measures and Presence (Continued)

Measure	Description	Significant Correlation	Presence Measure	Appendix A Reference
Dial task		Negative	PQ Involvement subscale	[Witmer, 1994a (1)]
Dial task		None	PQ	[Witmer, 1994a (2)]
Doorways task		None	PQ	[Singer, 1995]
Elevator task		None	PQ	[Witmer, 1994a (2)]
Flying-thru-Windows task		Negative	PQ Control Responsiveness/Distracton, Interface Awareness subscales	[Witmer, 1994a (1)]
Flying-thru-Windows task		Negative	PQ Total, Control Responsiveness, Interface Awareness subscales	[Witmer, 1994a (2)]
Reaction (choice) task		None	PQ	[Snow, 1996 (1)]
Reaction (choice) task		None	PQ	[Snow, 1996 (2)]
Reaction (choice) task		None	PQ	[Snow, 1996 (3)]
Reaction (choice) task		None	Magnitude estimation ratio-scale	[Snow, 1996 (1)]
Reaction (choice) task		None	Magnitude estimation ratio-scale	[Snow, 1996 (2)]
Reaction (choice) task		None	Magnitude estimation ratio-scale	[Snow, 1996 (3)]
Reaction (choice) task		Negative	PQ Total, Involvement, Control Responsiveness, Sensory Awareness subscales	[Witmer, 1994a (1)]
Reaction (choice) task		None	PQ	[Witmer, 1994a (2)]
Reaction (simple) task		Negative	PQ Total, Involvement, Control Responsiveness, Sensory Awareness subscales	[Witmer, 1994a (1)]
Reaction (simple) task		Negative	PQ Involvement subscale	[Witmer, 1994a (2)]
Search task		Negative	PQ	[Snow, 1996 (1)]
Search task		None	PQ	[Snow, 1996 (2)]
Search task		Negative	PQ	[Snow, 1996 (3)]
Slide task		Negative	PQ Total, Sensory Exploration, Control Responsiveness/Distracton, Involvement subscales	[Witmer, 1994a (1)]
Slide task		Negative	PQ Total, Sensory Exploration, Interface Awareness subscales	[Witmer, 1994a (2)]
Target (stationary/moving)		None	PQ	[Witmer, 1994a]
Turns task		Negative	PQ	[Snow, 1996 (1)]
Turns task		None	PQ	[Snow, 1996 (2)]
Turns task		Negative	PQ	[Snow, 1996 (3)]

Where several different types of performance measures are used for a task, it is not always clear which is the most important and, therefore, the relative importance of the different findings is uncertain. Findings from the VEPAB tasks do provide some evidence that the potential importance of presence depends on the types of activities to be performed in a VE. This is a reminder that looking at findings across studies can be misleading. And, of course, these studies used different VE interfaces and had participants drawn from different subject pools.

Finally, two studies examined the potential relationship between co-presence and task performance. For each of these very different tasks, performance measures, and co-presence measures, a positive correlation was found between task performance and co-presence. These two studies are identified in Table 19. Additional research is needed to determine whether these two studies are special cases or, indeed, relationships between task performance and co-presence are more frequent than those between task performance and presence. Since much of military training involves teams working together, this is an area of particular importance.

4.2 Relationship with Task-Related Characteristics

As in previous cases, it is difficult to provide a quantitative feel for the relationships between task-related measures and presence. Relationships with (place) presence have been reported for thirty-five studies, and with co-presence for eight studies (five of these fall into the previous group as well). No data are reported in the literature about any relationships between task-related measures and social presence.

Table 20 identifies the studies relevant for (place) presence. There are sixty-two different findings. The largest proportion (twenty-four) of these findings relate to the occurrence of simulator sickness symptoms. All but five of these findings are based on the use of Kennedy et al. Simulator Sickness Questionnaire (1993), giving a good basis for comparison. Of the seventeen studies that looked for a relationship between simulator sickness symptoms and the Witmer-Singer PQ, all but one found a significant negative relationship. Thus, if the assumption that presence has a causal influence on task performance holds, these data provide strong evidence for the importance of monitoring and reducing the occurrence of simulator sickness symptoms. However, the four findings related to the SUS Questionnaire were mixed, ranging from significantly positive to significantly negative relationships. The one psychological and one observed reaction presence measures used each failed to show a relationship between simulator sickness and presence. Nevertheless, simulator sickness is a potentially serious problem.

Stanney, Kennedy, and Kingdon (2000) review data that, for susceptible participants, indicate symptoms increase with the intensity and duration of a VE experience. They also report on motion sickness studies that have found that repeated exposures can reduce the occurrence of simulator sickness symptoms. They recommend steps for assessing the likelihood of whether a particular VE application is more prone to stimulate simulator sickness, and how this problem may be reduced. They also identify personal characteristics that may affect susceptibility. Their VE usage protocol is strongly recommended to aid in minimizing risks to VE users.

Table 19. Relationships between Performance Measures and Co-Presence

Measure	Description	Significant Correlation	Co-Presence Measure	Appendix A Reference
Accuracy	Proportion of time ring did not intersect wire	Positive	Basdogan's questionnaire	[Basdogan, 2000]
	# objects/movements correctly identified	Positive	Bystrom's questionnaire	[Bystrom, 1999]

Table 20. Relationships between Task-Related Measures and Presence

Measure	Description	Significant Correlation	Presence Measure	Appendix A Reference
Ability to get around, getting lost	Self-rating	Positive (1 item)	Barfield's questionnaire	[Barfield, 1993 (1)]
Accord (individual)	7-item questionnaire	Positive	2-item SUS Questionnaire	[Slater, 2000b]
Accord (group)	5-item questionnaire	Positive	2-item SUS Questionnaire	[Slater, 2000b]
	5-item questionnaire	None	2-item SUS Questionnaire	[Tromp, 1998 (2)]
Association with virtual body	1 item on extent of association	Positive	3-item SUS Questionnaire	[Usoh, 1999]
	1 item on extent of association	Positive	Fear Response	[Usoh, 1999]
Attention	Hit-to-signal ratio in VE	Negative	PQ	[Riley, 2001]
	Hit-to-signal ratio VE/RE	None	PQ	[Riley, 2001]
Collaboration	1 item on extent of collaboration	Positive (immersed)	2-item Questionnaire VR	[Axelsson, 1999]
		None (desktop)		
Communication	14-item questionnaire	None	5-item SUS Questionnaire	[Casanueva, 2001 (1)]
	1 item on naturalness of communication	None	2-item Questionnaire VR	[Axelsson, 1999]
Cross-modal visual-to-aural illusions	1-item questionnaire	None	Biocca's questionnaire	[Biocca, 2001a]
Cross-modal visual-to-haptic illusions	1-item questionnaire	Positive	Biocca's questionnaire	[Biocca, 2001a]
Engagement	Self-rating	Positive (1 item)	Barfield's questionnaire	[Barfield, 1993 (1)]
	1 item rating of enjoyment	Positive (1 item)	Barfield's questionnaire	[Barfield, 1993 (1)]
	Each of two 1-item ratings of enjoyment	Positive	2-item Barfield questionnaire	[Barfield, 1993 (2)]
	1 item rating of enjoyment	Positive	11-item Bystrom questionnaire	[Bystrom, 1996]
Adjectival Response Scale	Adjectival Response Scale	Positive	PQ Total, Involved/Control subscale	[Nichols, 2000 (1)]
		Positive	PQ Interface subscale	[Nichols, 2000 (2)]
Report of positive experience	1 item rating overall enjoyment	Positive	PQ Total, Involved/Control subscale	[Nichols, 2000 (2)]
		Positive	IPQ	[Regenbrecht, 1998]
Experienced fear	State-Trait Anxiety Index	Positive	PQ Interface subscale	[Youngblut, 2002]
Fatigue	Self-rating	Negative		

Table 20. Relationships between Task-Related Measures and Presence (Continued)

Measure	Description	Significant Correlation	Presence Measure	Appendix A Reference
Self-rating		None	SUS Questionnaire	[Youngblut, 2002]
Image clarity	Self-rating	Positive (1 item)	Barfield's questionnaire	[Barfield, 1993 (1)]
Loss of realism	Responses to open-ended questions	Negative	SUS Questionnaire	[Slater, 1993a]
Orientation in virtual world	Self-rating	Positive (1 item)	Barfield's questionnaire	[Barfield, 1993 (1)]
Simulator sickness	SSQ Total	Negative	PQ Total, Involved/Control subscale	[Allen, 2001]
	SSQ Oculomotor Discomfort subscale	Negative	PQ Total, Involved/Control, Natural subscales	[Allen, 2001]
	SSQ Disorientation subscale	Negative	PQ Natural subscale	[Allen, 2001]
	SSQ	Negative	PQ	[Bailey, 1994 (1)]
	SSQ	Negative	PQ	[Bailey, 1994 (2)]
	SSQ	Negative	PQ	[Kner, 1994 (1)]
	SSQ	None (for HMD)	SUS Questionnaire	[Mania, 2001]
	Short Symptom Checklist (SCC)	None (for HMD)	Startle response	[Nichols, 2000 (1)]
	SSC	None (for HMD)	Background awareness	[Nichols, 2000 (1)]
	SSC	None (for HMD)	Nichols's questionnaire	[Nichols, 2000 (1)]
	SSQ Total and all subscales	Negative	PQ Interface Quality subscale	[Nichols, 2000 (2)]
	SSQ Total, Disorientation, Oculomotor subscales	Negative	PQ Interface Quality subscale	[Singer, 1997]
	SSQ	None	PQ	[Singer, 1995]
	1-item rating of nausea	Positive	3 item SUS Questionnaire	[Slater, 1995a]
	1-item rating of dizziness, sickness, nausea	Negative	6-item SUS Questionnaire	[Uno, 1997]
	SSQ	Negative	PQ	[Witmer, 1996 (1)]
	SSQ Total and all subscales	Negative	PQ Control Responsiveness subscale	[Witmer, 1994a (1)]
	SSQ Total	Negative	PQ Total, Involvement, Control Responsiveness, Sensory Exploration subscales	[Witmer, 1994a (2)]
	SSQ Nausea subscale	Negative	PQ Control Responsiveness, Sensory Exploration subscales	[Witmer, 1994a (2)]
	SSQ Oculomotor subscale	Negative	PQ Total, Sensory Exploration, Involvement subscales	[Witmer, 1994a (2)]
	SSQ	Negative	PQ	[Witmer, 1994b (1)]
	SSQ Total and all subscales	None	SUS Questionnaire	[Youngblut, 2002]
	SSQ Oculomotor subscale	Negative	PQ Total, Involved subscale	[Youngblut, 2002]
	SSQ Total	Negative	PQ Involved subscale	[Youngblut, 2002]

Table 20. Relationships between Task-Related Measures and Presence (Continued)

Measure	Description	Significant Correlation	Presence Measure	Appendix A Reference
Situation awareness	SAGAT	None	PQ	[Riley, 2001]
Task completion time	Minutes	None	OPQ Total and all subscales	[Stevens, 2002]
Task ease	Self-rating	Positive	11-item Bystrom questionnaire	[Bystrom, 1996]
	Self-rating	Positive	Romano's questionnaire	[Whitelock, 2000]
Task performance rating	Self-rating	Positive	Romano's questionnaire	[Romano, 1998]
	1-item rating of performance	None	PQ, SUS Questionnaire	[Usuh, 2000]
Time spent in VE	Elapsed time	Positive	PQ Total, Involvement/Control subscale	[Singer, 1997]
	Elapsed time	Positive	Magnitude estimate ratio-scale	[Snow, 1996 (1)]
Workload	Elapsed time	None	Magnitude estimate ratio-scale	[Snow, 1996 (2)]
	Elapsed time	Positive	Magnitude estimate ratio-scale	[Snow, 1996 (3)]
	Modified Cooper-Harper scale	Negative	PQ	[Riley, 2001]
	NASA Task Load Index	Negative	PQ	[Riley, 1999]

Table 21. Relationships between Task-Related Measures and Co-Presence

Measure	Description	Significant Correlation	Co-Presence Measure	Appendix A Reference
Accord (individual)	7-item questionnaire	Positive	Steed's questionnaire	[Steed, 1999]
	7-item questionnaire	Positive	Slater's questionnaire	[Slater, 2000b]
Accord (group)	5-item questionnaire	Positive	Slater's questionnaire	[Slater, 2000b]
	5-item questionnaire	Positive	Slater's questionnaire	[Tromp, 1998 (2)]
Anxiety (of partner)	Social Anxiety Test	Positive	Basdogan's questionnaire	[Basdogan, 2000]
	1 item on communication extent	Positive	1-item Axelsson's questionnaire	[Axelsson, 1999]
Collaboration	Self-rating	Positive	Romano's co-presence items	[Romano, 1998]
	14-item questionnaire	Positive (high) Negative (low)	Casanueva's questionnaire	[Casanueva, 2001 (1)]
Communication	1 item on naturalness of communication	None	1-item Axelsson's questionnaire	[Axelsson, 1999]
Social anxiety of partner	Social Anxiety Test	Positive	Basdogan's questionnaire	[Basdogan, 2000]
Task performance rating	Rating 0-100	Negative for non-immersed, mixed for immersed (depending on audience type)	4-item SUS questionnaire	[Slater, 1999]

Although the studies summarized in Appendix A were selected because of their relevance to presence, some also provide data on the relationship between the occurrence of simulator sickness symptoms and technological or personal characteristics, and task performance itself. These are not the full set of studies that have examined the role of simulator sickness symptoms, so care must be taken not to form any generalized conclusions based on the subset of available data given here. Four studies (Allen, 2001; Larsson, 2001; Lok, 2003; and Zimmons 2003) identified three technological factors that showed a relationship with such symptoms and another two that didn't.

Wiederhold et al. (2001) found different relationships for two measures of cognitive type. Interestingly, in two studies (Singer, 1997, 1995) Singer and his colleagues found no correlation with post VE experience symptoms and their ITQ in one study, and a significant negative correlation in the other. With respect to task performance, Bailey and Witmer (1994) found mixed relationships between simulator sickness symptoms and measures of route and configuration knowledge, while Witmer et al. (1996) found none. A study by Youngblut and Perrin (2002) also found no significant correlation between the occurrence of simulator sickness symptoms and performance on a training transfer maintenance task. We are not aware of any evidence that relationships between the experience of simulator sickness in VEs and task performance are causal, though such a relationship would appear to have face validity. Any relationships among presence, simulator sickness, and task performance are probably complex.

The next most commonly examined task-related measure is enjoyment. Here, five studies consistently found a significant positive correlation, using three different presence questionnaires. Should presence exert a causal influence in this relationship, these data indicate the potential importance of presence in ensuring user acceptance of VE applications, provide guidance for the design of VE applications and, of course, give some indication of the types of applications best suited for VEs. Findings for a relationship between time spent in the VE and presence were only slightly less consistent, with three of four findings showing a significant positive relationship. These data are difficult to interpret given the findings that increased duration leads to increased simulator sickness symptoms that, in turn, leads to less presence. Though there are only two studies in the following cases, consistent results were also found for a significant correlation between each of self-rating of task ease (positive) and workload (negative) with presence. Again, based on the results of only two studies each, findings for a relationship between presence and each of group accord, collaboration, and self-rating of task performance were mixed.

The seven studies that examined task-related measures and co-presence are identified in Table 21. Only three task-related measures were examined in two or more studies: individual accord, group accord, and collaboration. In all these cases, a significant positive correlation was found with co-presence, except for participants who reported a low level of collaboration. Most of the task-related measures examined in this set of studies are a subset of those considered when looking for relationships with (place) presence, but only findings for individual accord and communication were the same.

Some of the task-related measures examined have greater implications for task performance than others. Unfortunately, there is a lack of data about how closely they are related.

4.3 The Question of Causal Relationships

Why is the assumption of a causal link between presence and task performance so pervasive? For some learned tasks whose performance has become largely automatic, a high sense of presence in our surroundings is often unnecessary. Indeed, the only theory of presence that explicitly

addresses both presence and task performance is Draper, Kaber, and Usher's (1999) Structured Attentional Resource Model that demonstrates no direct relationship between the two. Not only may presence and task performance vary independently but, if there is a relationship, the competition for attentional resource may result in a negative relationship. In the primary domain of interest here, military training, however, the idea that a greater sense of presence during training in a virtual world will increase positive transfer of learning to real world tasks has high face validity.

The data presented earlier in this section only indicate whether a correlation was found between the sense of presence and some type of task or performance measure. They do not indicate whether any of these relationships were causal, that is, a change in the level of presence experienced resulted in a change in task performance. For a causal relationship, not only must there be some degree of correlation between presence and task performance, but if presence changes then task performance also changes when *everything else is unchanged*. This last phrase is crucial and usually referred to as the *ceteris paribus* condition. Generally, it is extremely difficult to ensure that the factor used to manipulate presence has no direct effect on performance. Even then, it may be uncertain whether a relationship arises from some additional unknown factor(s) that influences both presence and task performance. Indeed, Mullen and Roth (1991) suggest that the statement "X causes "Y" should really be considered as "X causes Y with some degree of probability."

Only one study that explicitly looked for such a relationship has been found in the literature. Termed a pilot study, this work was conducted by Welch (1999) and his colleagues. The experimental task required each participant to drive a virtual car and collide with some virtual cubes while avoiding others. In one condition, there were no audio cues, while in the second condition participants heard the sound of screeching tires. Presence was measured using a simple rating scale (1 to 100%) and the performance measure was the number of (correct) cubes collided with in a fixed amount of time. Other than reporting the use of an HMD visual display, few details are given. There is no information, for example, on the number of participants. Welch reports that although the audio cues did significantly increase the sense of presence experienced, there was no significant difference in the performance scores for each condition. The small difference (10%) in presence found between conditions led Welch to report these results as only suggestive and recommend further studies using an experimental factor that has a greater influence on presence. Unfortunately, it is extremely difficult to identify such factors without extensive experimentation. The tables presented in Section 3 identify characteristics that have shown a relationship with presence. All of these are potential candidates for use in examining causality, though some seem more likely or, at least easier to manipulate, than others.

Given a causal relationship, there are additional concerns to consider. For example, the ability to feel a high sense of presence in a VE seems to be influenced by several technological characteristics that are expensive to improve, in terms of both hardware and necessary software development. This will raise issues of cost-benefit tradeoffs. Nor do we mean to imply that higher presence is always necessary. It seems likely that level of presence needed to, for example, determine whether the design of an aircraft engine allows maintenance workers sufficient access to perform necessary tests may be more than that required by biomedical engineers examining possible drug interactions at the molecular level.

Additional research is urgently needed to determine whether, when, and for whom presence is important.

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Acronyms and Abbreviations

ADL	Advanced Distributed Learning
BIP	Breaks in Presence
DoD	Department of Defense
FOV	Field of view
HMD	Head-mounted display
IDA	Institute for Defense Analyses
IPQ	Igroup Presence Questionnaire
ITQ	Immersive Tendencies Questionnaire
MCQ	Memory Characteristic Questionnaire
OPQ	Object Presence Questionnaire
PQ	Presence Questionnaire
SOPI	Sense of Presence Inventory
SSC	Short Symptom Checklist
SSQ	Simulator Sickness Questionnaire
SUS	Slater, Usoh, and Steed
SVUP	Swedish Viewer-User Presence
UCL	University College, London
VE	Virtual Environment
VEPAB	Virtual Environment Performance Assessment Battery
VERTS	Virtual Emergency Response Training System
VR	Virtual Reality
VRUSE VR	Usability Questionnaire

Appendix A. Summaries of Experiment Studies

Appendix A. Summaries of Experiment Studies

This appendix summarizes experimental studies that have examined the relationships between various factors and presence, the reliability and validity of presence measures, and relationships between presence and task performance. As appropriate, and information was available, the same details are provided for each study:

Factors:	Identification of the experimental conditions that were manipulated.
Computing platform:	Identification of the hardware and software platform.
Visual display:	Identification of visual display device(s) used.
Audio display:	Identification of device(s), or methods used, to present sound cues.
Haptic display:	Identification of the device(s) or methods used to present tactile or force feedback cues.
Olfactory display:	Identification of device(s) or methods used to present olfactory cues.
Tracking:	Identification of the device(s) or methods used to track the position of various body parts.
Navigation	Identification of the device(s) or methods used to navigate through a virtual world.
Object manipulation:	Identification of the device(s) or methods used to manipulate virtual objects.
Virtual world:	Description of the virtual world(s) used, including indication of the level of detail represented, and any method of participant self-representation.
Training:	Description of activities used to familiarize participants with the use of VE interfaces.
Experimental task:	Description of the task that participants were asked to perform, with an indication of the level of interaction required and any time constraints.
Participants:	Description of the participant sample and any screening requirements.
Study design:	Specification of whether a within-subjects or between-subjects experimental design was used.
Presence measures:	Identification of the measure(s) used to assess presence.
Person-related measures:	Identification of measure(s) used to assess personal characteristics.
Task-related measures:	Identification of measure(s) used to capture outcomes not directly related to task performance.
Performance measures:	Identification of measure(s) used to assess performance on required tasks.
Findings:	Description of findings.

In the following, only significant effects or correlations are reported, and only for first-level interaction effects. Also, please note some of the descriptions of experimental studies contain data not directly relevant to presence; these details are shown in *italics*.

[Allen, 2001] Allen, R.C. and M.J. Singer. 2001. *Presence in Altered Environments: Changing Parameters and Changing Presence*. U.S. Army Research Institute for the Behavioral and Social Sciences, Orlando, FL. See also Allen (2000).

Factors:	Environment type (virtual 48° × 36°, real Restricted 48° × 36°, real Horizontal Visual Field 96° × 36°, real Lower Visual Field 48° × 72°, real Normal), self-representation (body, right hand and fanny pack when 2 feet from a trash can).
Computing platform:	SGI Onyx RealityEngine2 with 8 200 MHz R4400 processors, 256 MB RAM. Software Systems Multigen II v1.5 and in-house software.
Visual display:	For VE: Virtual Research Corp. V8 HMD with FOV 48° × 36°, 1820 × 480 color pixels per eye. Participant eye height and Inter-Pupillary Distance (IPD) used to adjust display. For real world: HMD mockup with plastic goggles including cardboard cutouts for masks.
Auditory display:	Sound of collisions and white noise presented over HMD headphones.
Tracking:	For VE: Head, shoulder, feet, right arm, and right hand motions using 6 Ascension Technologies Flock-of-Birds sensors and tracked by an Ascension Technologies MotionStar (wired version) with an extended range transmitter. For real world: Precision Navigation Inc. TCM2/50 Electronic Compass Module mounted on HMD mockup.
Navigation:	Walking in place.
Object manipulation:	In VE used joystick to move virtual hand close to fanny pack and pick up, then drop, a virtual ball. In real world used real balls carried in a fanny pack,
Virtual world:	Series of 3 rooms filled with typical office furniture. Self-representation as virtual body or virtual right hand (and fanny pack).
Training:	Movement training in 2 separate practice environments, included general movement (VE condition only), collision avoidance, path following. Then, in one practice environment, search training involving locating 2 trash can targets in sequential order and dropping a ball inside each.
Experimental task:	For guided movement task, in first room follow a path defined by arrows as quickly and accurately as possible, minimizing collisions. For search task, in each remaining room, search for 2 trash can targets in sequential order and drop a ball inside each.
Participants:	90 participants recruited from a university campus; 36 males, 54 females; age range 18 to 45, mean 21 years. Normal color vision, normal stereo vision, normal acuity (20/20 – 20/30, normal or corrected), and normal horizontal peripheral vision in each eye (70° or better). Met health and simulator sickness screening conditions.
Study design:	Between-subjects. 2 groups performed tasks in the virtual environment, 4 groups in the real environment.
Presence measures:	32-item Witmer-Singer Presence Questionnaire (PQ) Version 3.0.
Person-related measures:	Immersive Tendencies Questionnaire (ITQ). <i>Motion Sickness Questionnaire (MSQ)</i> .
Task-related measures:	Simulator Sickness Questionnaire (SSQ).
Performance measures:	<i>Guided movement time, number of collisions, search time.</i>
Other measures:	<i>Head movement (yaw, pitch).</i>
Findings:	<ol style="list-style-type: none"> (1) Self-representation had a significant effect on presence only for PQ Natural subscale, with users rating disembodied condition as more natural than avatar condition. (2) Environment type had a significant effect on PQ Total and all except Natural subscale scores, with VE users reporting significantly more presence than Restricted condition users. (3) FOV in real world had a significant effect on PQ Total and all except Involved/Control subscale, where Normal group rated Interface Quality higher than

- Restricted and Lower Visual Field groups, and Normal group rated total PQ, Naturalness, and Resolution higher than Restricted group.
- (4) For real world participants, FOV had a significant positive correlation with PQ Total and Natural, Interface Quality, and Resolution subscales.
 - (5) For VE participants, ITQ Focus subscale scores had a significant positive correlation with PQ Total, Involved/Control and Interface Quality subscale scores, and ITQ Games subscale scores had a significant positive correlation with PQ Total and Involved Control subscale scores. For real world participants, ITQ Games subscale scores had a significant positive correlation with PQ Resolution subscale scores.
 - (6) For VE participants, SSQ total score had a significant negative correlation with PQ Total and Involved Control subscale scores; SSQ Oculomotor Discomfort with PQ Total, Involved/Control, and Natural subscales; and SSQ Disorientation with PQ Natural subscale. For real world participants, SSQ total and subscale scores had no significant correlations with PQ Total and subscale scores.
 - (7) *For the guided movement task, self-representation had a significant effect on time taken, with the Body group taking significantly longer. Time taken by the disembodied group also was significant different to time taken by the Restricted group. Self-representation had no significant effect on collision score or head movement; in each case the score for the (pooled) VE groups differed significantly from that of the Restricted group.*
 - (8) *For the search task, self-representation had no significant effect on time taken, collision score or head movement; in each case, the score for the (pooled) VE groups differed significantly from that of the Restricted group.*
 - (9) *Self-representation had no significant effect on pitch or yaw, or on change (pre, post exposure) in SSQ total or subscale scores.*
 - (10) *Type of environment/FOV showed a significant effect on post-exposure SSQ scores between the (pooled) VE and (pooled) real world groups only, with VE participants reporting significantly higher SSQ Total score, and higher Nausea, Oculomotor Discomfort, and Disorientation subscale scores.*
 - (11) *For VE participants, SSQ scores had a significant positive correlation with each of MSQ Total, subscale A, and subscale B with SSQ Disorientation.*

[Axelsson, 2001] Axelsson, A.-S., Å. Abelin, I. Heldal, R. Schroeder, and J. Wideström. 2001. "Cubes in the Cube: A Comparison of a Puzzle-Solving Task in a Virtual and a Real Environment." *CyberPsychology & Behavior*, 4(2), 279–286.

Factors:	Visual display (1 participant in 5-wall Cave and 1 using desktop system; 2 participants face-to-face in real world).
Computing platform:	SGI Onyx 2 Infinite Reality with 14 MIPS R10000 processors, 2 GB RAM, 3 graphics pipes. SGI O2 with 1 MIPS R10000 processor, 256 MB RAM. DVise 6.0 software with SGI Performer renderer.
Visual display:	3 × 3 × 3m TAN 3D Cube with projection on 5 walls (no ceiling), stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses. 19-inch monitor with FOV ~60°. Frame rate ≥30Hz.
Auditory display:	Communication via telephone headset.
Tracking:	Polhemus tracker attached to shutter glasses.
Navigation:	In the Cube system: by moving around physically and gesturing with DVise 3D mouse. In the desktop system: by moving middle button on standard 3-button 2D mouse.
Object manipulation:	In the Cube system: blocks selected and moved by a participant putting his hand into a virtual cube and pressing 3D mouse button. In the desktop system: blocks selected by clicking on the cube with the left button, then moved by keep right

	button pressed and moving the mouse; cubes rotated using a combination of the right mouse button and shift key.
Virtual world:	Empty room containing 8 blocks with 1 of 6 different colors on each side. Blocks were 30 cm each edge. Self-representation as identical dVise avatars.
Experimental task:	Two participants cooperate to solve a puzzle by arranging blocks into a cube such that each side of the completed cube displays a single color. 20 minute time limit.
Participants:	22 pairs of participants; 26 males, 18 females; mean age 34 years.
Study design:	Between-subjects. Task performed first in the VE with one user in Cave and the other using a desktop, then in real world.
Presence measures:	3-item Questionnaire VR, 2-item Axelsson's co-presence questionnaire.
Task-related measures:	2-item questionnaire on own and partner's contribution to task, 1-item on amount of verbal communication, 1-item on extent of collaboration.
Findings:	<ol style="list-style-type: none"> (1) Visual display had a significant effect on presence, with CAVE users reporting more presence; but had no significant effect on co-presence. (2) Co-presence had a significant positive correlation with presence in the desktop environment, but not in the Cave environment. (3) <i>Visual display had a significant effect on contribution, with increased contribution reported for Cave display.</i> (4) <i>Visual display had no significant effect on amount of communication.</i> (5) <i>Visual display had no significant effect on collaboration between Cave and desktop system, but a significant effect for real and virtual environments with more collaboration reported for real environment.</i>

[Axelsson, 1999] Axelsson, A.-S., Å. Abelin, I. Heldal, A. Nilsson, R. Schroeder, and J. Wideström. 1999. "Collaboration and Communication in Multi-User Virtual Environments: A Comparison of Desktop and Immersive Virtual Reality Systems for Molecular Visualization." In *Proc. 6th UKVRSIG Conference*, September, Salford, UK. 107–117.

Factors:	Visual display (5-wall Cave, desktop).
Computing platform:	SGI Onyx2 Infinite Reality with 8 MIPS R10000 processors, 2 GB RAM, 3 graphics pipes. SGI O2 with 1 MIPS R10000 processor, 256 MB RAM. DVise 6.0 software with SGI Performer renderer, Lake Huron 3.0 for audio.
Visual display:	3 × 3 × 3m TAN 3D Cube with projections on 5 walls (no ceiling), stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses; frame rate 4–6Hz. 19-inch monitor with frame rate 3–4Hz.
Auditory display:	8 loudspeakers and a Vibrafloor used in the Cave system.
Tracking:	Polhemus tracker attached to shutter glasses.
Navigation:	In the Cube system: using DVise 3D mouse. In the desktop system: by moving middle button on standard 2D mouse.
Object manipulation:	Use of a mouse button to mark objects in the desktop system.
Virtual world:	Open space containing ball-and-stick molecular models of similar size (1200 atoms); Myoglobin in Cube system and Cytochrome-2 in desktop system. Unique sounds associated with the amino acids and iron atom in the Cave system.
Training:	Demonstration and practice in how to navigate and manipulate objects in the VE, and how to communicate with partner. 5–10 minutes.
Experimental task:	First locate the single iron atom within the molecule and identify the atoms connected to it. Then count the number of carbon rings in the molecule. 15 minutes allowed for each task.
Participants:	100 university undergraduates, working in groups of strangers (4–6 in the Cave-type display, pairs with the desktop system). Data for co-presence, collaboration, and communication were collected for only the navigator and his collaborator in the Cube system (40 participants), other participants were bystanders.
Study design:	Within-subject.
Presence measures:	2-item Questionnaire VR, 1-item Axelsson's co-presence questionnaire.

Task-related measures: 1 item on extent of experienced collaboration, 1 item on naturalness of communication, 1 item on leadership, 1 item on pleasantness, 1 item on enjoyment.

- Findings:
- (1) Visual display had a significant effect on presence, with Cave users reporting more presence, but no significant effect on co-presence.
 - (2) In the immersive system, presence had a significant positive correlation with co-presence and collaboration, but not communication. In the desktop system, no significant correlations between presence and any of co-presence, collaboration, or communication.
 - (3) In the both systems, co-presence had a significant positive correlation with collaboration, but not communication.
 - (4) *Visual display had no significant effect on each of communication, collaboration, or leadership.*
 - (5) *Visual display had a significant effect on rating of pleasantness and enjoyment, with increases in each found for the Cube display.*
 - (6) *Collaboration had a significant positive correlation with communication for both types of display.*

[Bailenson, 2001] Bailenson, J.N., J. Blascovich, A.C. Beall, and J.M. Loomis. 2001. "Equilibrium Theory Revisited: Mutual Gaze and Personal Space in Virtual Environments." *Presence*, 10(6), 583–598.

- Factors: Agent realism of facial model (photographic texturing, flat shaded), agent realism of gaze behavior (eyes closed, eyes open, blinking, blinking and directing gaze to participant, blinking and directing gaze to participant as well as eye dilation when participant stepped within 0.75m), gender.
- Computing platform: 450 MHz Pentium III dual-processor, with Evans & Sutherland Tornado 3000 dual-pipe graphics card. System latency maximum of 65ms.
- Visual display: Virtual Research V8 stereoscopic HMD with resolution 680 × 480, FOV 50°H × 38°V. Frame rate 36Hz. Participant eye height used to adjust display.
- Tracking: Head tracking using Intersense IS300 and in-house passive optical position sensing system.
- Navigation: Walking around.
- Object manipulation: None.
- Virtual world: 7.2 × 6.4 × 4.5m room with either a pylon or an agent standing inside. Agent represented as a Caucasian male, 3D polygonal model, 1.85m tall, and wearing a label on the front on the front on his shirt giving his name and a back label listing a number, both in text easily readable from 1 m. Different colored shirt and hair, and different name and number for each trial. No collision detection. No self-representation. In control condition, a pylon replaced the agent, same height as agent, with color and labels changing. 10 trials, with each block of 5 trials taking 5 to 15 minutes.
- Training: Walking round empty virtual room for approx. 1 minute.
- Experimental task: Read number of back of shirt, then name on front.
- Participants: 50 introductory psychology students; 26 males and 24 females; age range 18 to 31 years. (Ten participants used in control condition with pylon.)
- Study design: Within-subjects for face model, between-subjects for gaze behavior, gender.
- Presence measures: Bailenson's 5-item social presence questionnaire (taken in 2 additional trials: 1 with photograph texture face, 1 with flat-shaded face; not completed by control condition participants).

Person-related measures: Gender.

Performance measures: *Percent correct when matching of names to numbers.*

- Findings:
- (1) Realism of face model had no significant effect on any study measure.
 - (2) Realism of gaze behavior had a significant positive effect on social presence for females only.
 - (3) Gender had no significant effect on social presence.

- (4) *Realism of gaze behavior and gender each had no significant effect on memory test.*

[Bailey, 1994 (2)] Bailey, J.H. and B.G. Witmer. 1994. "Learning and Transfer of Spatial Knowledge in a Virtual Environment." In *Proc. Human Factors and Ergonomics Society 38th Annual Meeting*. 1158–1162.

Factors: Training type (exploratory, restrictive), head tracking (present, absent).
Computing platform: SGI Crimson Reality Engine. Software Systems Multigen and Sense8 Corp. WorldToolKit.
Visual display: Stereoscopic, color Virtual Reality Flight Helmet.
Tracking: Head tracking.
Navigation: Using standard video game joystick.
Object manipulation: None.
Virtual world: Building.
Training: None.
Experimental task: 3 rehearsals of circuitous route in VE using instructional strategy either based on finding and following successive landmarks (exploratory) or following left/right style directions (restrictive). Participants tested in actual building.
Participants: 64 participants: 32 males, 32 females.
Study design: Between-subjects.
Presence measures: 32-item Witmer-Singer PQ Version 2.0.
Person-related measures: Witmer-Singer 29-item ITQ Version 2.0.
Task-related measures: Kennedy SSQ.
Performance measures: Route knowledge: time taken to complete rehearsal, time spent in decision areas, time in stairways, number of collisions, time spent in collisions, time spent looking at landmarks, attempted number of attempted wrong turns, distance traveled, scores on ordering route photographs. Building configuration knowledge: measured using paper-based and CRT-based projection convergence technique for triangulating 4 targets from 3 sighting locations.
Findings: (1) Training type and head tracking each had no significant effect on presence.
(2) ITQ scores had a significant positive correlation with presence.
(3) Simulator sickness had a significant negative correlation with presence.
(4) Route knowledge only as assessed by photograph ordering test had a significant positive correlation with presence.
(5) Configuration knowledge only as assessed by accuracy on paper convergence test had a significant positive correlation with presence.
(6) *Training type had a significant effect on route photograph ordering with exploratory condition leading to better results.*
(7) *Training type had a significant effect on time taken (using only participants who did not experience simulator sickness) and count of wrong turns, with restrictive condition taking less time but making more wrong turns.*
(8) *Head tracking had a significant interaction with training type, such that restricted participants learned the configuration best without head-tracking, also a significant effect on rate of learning showing less time*
(9) *Rehearsal trial had a significant negative effect on each of time spent in decision areas, time to complete rehearsal, time in stairways, time spent looking at landmarks, number of attempted wrong turns.*
(10) *ITQ scores had no significant correlation with any performance measure.*
(11) *SSQ scores had a significant positive effect on route completion time and CRT-based projective convergence test, and a significant negative correlation with photo-ordering accuracy.*

[Barfield, 1998] Barfield, W., K.M. Baird, and O.J. Bjorneseth. 1998. "Presence in Virtual Environments as a Function of Type of Input Device and Display Update Rate." *Displays*, 19(2), 91–98.

Factors: Update rate (10, 15, 20Hz), navigation (3DOF joystick, 3DOF SpaceBall).
Computing platform: SGI Indigo Extreme R4400 graphics workstation. In-house software with objects designed using Lambertian-shaded, 4-sided polygons of different shapes and sizes. Gouraud shading and ambient light model.
Visual display: GE-610 6 × 8ft rear projection screen, stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses. Imagery generated at 1280 × 512 pixel resolution, 70° FOV and GFOV. Eyepoint elevation 110 cm. Subject seated.
Navigation: Measurement Systems Inc. model 544 3DOF joystick or Spatial Systems SpaceBall model 1003 3DOF spaceball.
Object manipulation: None.
Virtual world: Virtual Stonehenge in a night setting. Menhirs constructed of 4- and 6-sided polygons of different sizes and shapes. Ground was green, sky navy blue with stars, Stonehenge edifices beige. Passive ambient night sounds.
Training: Two 4-minute training sessions in Virtual Stonehenge.
Experimental task: Navigate site and search for a rune inscribed on one side of a menhir. 2 minute time limit.
Participants: 8 participants; 5 males, 3 females; mean age 30 years. Regular and infrequent computer users, some with prior VE experience. Normal or corrected-to-normal visual acuity, normal hearing.
Study design: Within-subjects.
Presence measures: Barfield's presence questionnaire.
Findings: (1) Update rate had a significant positive effect for 13 items on presence questionnaire. 15–20Hz critical value.
(2) Navigation device had no significant effect on presence.

[Barfield, 1995] Barfield, W. and C. Hendrix. 1995. "The Effect of Update Rate on the Sense of Presence within Virtual Environments." *Human Factors*, 1(1), 3–16.

Factors: Update rate (5, 10, 15, 20, 25Hz).
Computing platform: SGI Indigo Extreme workstation. Objects Lambertian shaded, designed using 4-sided polygons of difference shapes and sizes.
Visual display: GE-610 6 × 8ft rear projection screen, stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses. Imagery generated with 1280 × 512 pixel resolution, GFOV 50°. Eyepoint elevation 110 cm. Subject seated with 90° FOV of screen. Black curtain to isolate viewing area.
Tracking: Polhemus 3Space Fastrak for head tracking.
Navigation: 3DOF flight stick located on table in front of participant.
Object manipulation: None.
Virtual world: Virtual Stonehenge (see [Barfield, 1998] above).
Training: Ten practice trials in the VE.
Experimental task: Navigate site and search for a rune inscribed on a wall. 2 minute time limit.
Participants: 13 participants; 9 males and 4 females, mean age 25.3 years. Some with experience in computer graphics and VEs. Normal or corrected-to-normal visual acuity.
Study design: Within-subjects.
Presence measures: 13-item Barfield's presence questionnaire, including overall rating question; questions categorized as: (1) presence, (2) fidelity of interaction.
Findings: (1) Update rate had a significant positive effect on presence, with less reported presence for 5 and 10Hz than for 20 and 25Hz when considering overall presence

rating and 3 other questions directly related to presence. No significant difference based on update rate for presence items related to awareness of the real world or simulation speed.

- (2) Fidelity of interaction had a significant positive correlation with presence
- (3) *Update rate had a significant positive effect on fidelity of interaction for all items, with increased fidelity for 20 to 25Hz compared with 5Hz.*

[Barfield, 1993 (1)] Barfield, W. and S. Weghorst. 1993. "The Sense of Presence within Virtual Environments: A Conceptual Framework." In G. Salvendy and M.J. Smith (Eds.), *Human-Computer Interaction: Software and Hardware Interfaces*. New York: Elsevier. 699–704.

Visual display: VPL EyePhones.
Tracking: Polhemus 6D tracker for hand tracking.
Navigation: VPL DataGlove.
Object manipulation: None.
Virtual world: Two virtual worlds: (1) Virtual Seattle; (2) 3 similarly complex environments differing in their use of a ground plane and other spatial landmarks, and in the visibility and degree of abstractness of objects.
Experimental task: Navigating through two virtual worlds.
Participants: 86 participants; age range 14–59.
Presence measures: 3 items of Barfield's questionnaire (part of 24-item survey questionnaire).
Person-related measures: Age, introspection, comfort with computers.
Task-related measures: Ratings of enjoyment, engagement, ease of navigation, display comfort, being lost, display color quality, image clarity, movement ease, orientation in VE.
Findings: (1) Enjoyment had a significant positive correlation with each of "Sense of being there," "Sense of inclusion in the virtual world," and "Sense of presence in the virtual world."
(2) Age had a significant negative correlation with "Sense of inclusion in the virtual world."
(3) (In order of decreasing strength) display comfort, comfort with computers, ease of navigation, being lost, overall enjoyment, display color quality, ability to get around each had a significant positive correlation with "Sense of being there."
(4) (In order of decreasing strength) overall enjoyment, overall comfort, introspection, ease of interaction, ease of navigation, movement ease each had a significant positive correlation with "Sense of inclusion."
(5) (In order of decreasing strength) orientation within the virtual world, being lost, engagement, color quality, image clarity, overall enjoyment, ability to get around each had a significant positive correlation between "Sense of presence."

[Barfield, 1993 (2)] Barfield, W. and S. Weghorst. 1993. "The Sense of Presence within Virtual Environments: A Conceptual Framework." In G. Salvendy and M.J. Smith (Eds.), *Human-Computer Interaction: Software and Hardware Interfaces*. New York: Elsevier. 699–704.

Visual display: VPL EyePhones.
Tracking: Polhemus 6D tracker for hand tracking.
Navigation: Joystick handle with embedded tracker.
Object manipulation: None.
Virtual world: Various simple VEs.
Experimental task: Designing 3D model and object dynamics for a VE, then navigating, exploring, and interacting with implemented VE.
Participants: 69 participants; age range 8 to 16, mean age 11.8 years.
Presence measures: 2 items of Barfield's questionnaire (part of 27-item survey questionnaire).
Task-related measures: Enjoyment of camp, enjoyment of designing/building a virtual world.

- Findings:
- (1) Enjoyment of designing and building a virtual world had a significant positive correlation with “feeling part of the virtual world.”
 - (2) Enjoyment of the technology camp had a significant positive correlation with “feeling part of the virtual world.”
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[Basdogan, 2000] Basdogan, C., C.-H. Ho, M.A. Srinivasan, and M. Slater. 1998. “An Experimental Study on the Role of Touch in Shared Virtual Environments.” *ACM Transactions on Computer Human Interactions*, 7(4), 443–460. See also Ho (1998).

- Factors: Haptic force feedback (present, absent).
- Computing platform: IBM compatible PC with dual Pentium II 300 MHz processors, 3D graphics accelerator. Open Inventor rendering software for visual display, in-house software for haptic rendering.
- Visual display: Two monitors.
- Haptic display: Two SensAble Technologies, Inc. PHANToM devices each providing force feedback to a single finger, haptic update rate 1 kHz.
- Object manipulation: PHANToMs slaved to ring with each contact point represented by a cursor positioned on the ring. Both partners press on the ring at the same time to hold it and move it.
- Virtual world: World consisted of bent wire strung between two end points. Ring positioned loosely over wire with blue/green cursors to denote participants’ contact points. Background of two walls positioned to form a back wall and floor. Wire and ring cast a shadow on the floor.
- Experimental task: Two participants at remote locations interact via haptic and visual displays to move a ring back and forth along a wire while minimizing or avoiding contact between the wire and the ring. Contact between wire and ring denoted by ring color and surrounding walls changing color.
- Participants: 10 participants who worked with the same unknown partner. Partner was an expert user expected to exhibit constant performance throughout trials.
- Study design: Within-subjects.
- Presence measures: Basdogan’s co-presence questionnaire.
- Person-related measures: Social anxiety test, age, gender, computer use.
- Task-related measures: Social anxiety assessment of partner.
- Performance measures: Proportion of time ring was not intersecting the wire.
- Findings:
- (1) Haptic force feedback had a significant positive effect on co-presence.
 - (2) Gender had a significant effect on co-presence, with females reporting higher co-presence.
 - (3) Age had a significant negative correlation with co-presence.
 - (4) Computer use had a significant positive correlation with co-presence.
 - (5) Participant’s social anxiety had a significant relationship with co-presence, negative for males, positive for females.
 - (6) Extent of social anxiety of partner had a significant positive correlation with co-presence.
 - (7) Task performance had a significant positive correlation with co-presence for the haptic force feedback condition only.
 - (8) *Haptic feedback had a significant positive effect on performance.*
 - (9) *Group had a significant interaction with condition, such that use of the visual system only first, followed by the visual and haptic system, resulted in better performance than the reverse order.*
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[Biocca, 2001a] Biocca, F., J. Kim, and Y. Choi. 2001a. “Visual Touch in Virtual Environments: An Exploratory Study of Presence, Multimodal Interfaces, and Cross-Modal Sensory Illusions.” *Presence*, 10(3), 247–265.

Computing platform:	SGI Onyx Reality Engine with 2 graphics pipes. Software Systems Multigen Smart Scene software.
Visual display:	Stereoscopic Virtual Research V8 HMD.
Tracking:	Polhemus magnetic tracking for head and hands.
Object manipulation:	Fakespace Labs Pinch gloves for using gestures to grab and move objects. A visual representation of a spring indicated that an object was being pulled away from its “snap” position. When pulled far enough, the spring was retracted and the object “popped” into participant’s hand.
Virtual world:	Environment 1: Media Interface & Network Design (M.I.N.D.) Lab’s Virtual Hands-on Cadaver Environment; 3D room resembling a doctor’s examining room, with examining table with a cadaver (realistic skeleton with 8 complete organs in rib cage) and medical charts on the wall. Environment 2: Similar to first environment, but with a collection of simple symmetrical polygonal shapes occupying the same space and location of the cadaver, matching the number of objects in the virtual cadaver. Hands represented as 3D cursors (blue transparent sphere with embedded tubular cross).
Training:	View recorded training session to provide basic instructions in how to navigate the environment and manipulate objects. Participants spent time in a training VE (an open city space) until they felt comfortable with that environment.
Experimental task:	In the experimental environment: remove all organs from the cadaver. In the control environment, remove symmetrical objects.
Participants:	77 university students.
Presence measures:	Biocca’s questionnaire.
Task-related measures:	Cross-modal visual-to-haptic and visual-to-aural illusions.
Findings:	(1) Reports of cross-modal visual-to-haptic illusions had a significant positive correlation with presence. (2) Reports of cross-modal visual-to-aural illusions had no significant correlation with presence.

[Botella, 1999] Botella, C., A. Rey, C. Perpiñá, R. Baños, M. Alcañiz, A. Garcia-Palacios, H. Villa, and J. Alozano. 1999. “Differences in Presence and Reality Judgment Using a High Impact Workstation and a PC Workstation.” *CyberPsychology & Behavior*, 2(1), 49–52.

Factors:	Level of equipment (SGI with FS5 HMD and 3D joystick, Pentium II with V6 HMD and 2D mouse).
Computing platform:	SGI high impact computer graphics workstation with Division dVISE software or Pentium II-based workstation with AccelEclipse Graphical Card with Sense8 WorldUp software.
Visual display:	High quality Virtual Research FS5 HMD or medium quality Virtual Research V6 HMD.
Navigation:	Using a Division 3D joystick or standard 2D mouse.
Virtual world:	Designed for treatment of claustrophobia, consisting of a room where participants could walk and open/close windows and doors, and a second smaller room where participants could walk and open/close the door and move one of the walls to narrow room dimensions.
Experimental task:	15-minute exposure.
Participants:	69 undergraduates; age range 19 to 35.
Study design:	Between-subjects.
Presence measures:	15-item Reality Judgment and Presence Questionnaire.
Findings:	(1) Level of equipment had no significant effect on presence or reality judgment.

[Bystrom, 1999] Bystrom, K.-E. and W. Barfield. 1999. “Collaborative Task Performance for Learning Using a Virtual Environment.” *Presence*, 8(4), 435–448.

Factors:	Collaboration (single user, pair), navigation (control of movement and navigation, control of movement only, control of navigation only, no control), head tracking (present, absent).
Computing platform:	SGI Indigo Extreme workstation. In-house software.
Visual display:	GE 610 6 × 8ft rear projection screen. Images displayed using Stereographics Corp. CrystalEyes shutter glasses with 1280 × 512 pixel resolution. Update rate 6 fps. Participants seated in front of projection screen so that their position subtended a 90° FOV with the display screen.
Tracking:	Polhemus 3Space Fastrak for head tracking.
Navigation:	Standard mouse controlled by participant with head-tracking, located on small table in front of participant. Participant who “controlled” navigation operated mouse or gave instructions to mouse controller.
Object manipulation:	None.
Virtual world:	Virtual room with objects such as tables, chairs, a desk, a bookshelf, a telephone, and a notepad. 6 versions of the room formed by relocating certain objects.
Experimental task:	Navigate through a virtual room, identify objects moved from position given on a provided diagram. Took diagram of room showing initial object locations into VE, along with additional diagram onto which marked changes of location. 2 treatments alone, 4 working with a partner. Each trial 3 minutes.
Participants:	20 participants recruited from university engineering classes, and software companies or associations; 10 males, 10 females; age range 16 to 49, mean age 28 years. 9 participants had previous VE experience, 5 for less than 10 minutes, 4 for over 20 minutes. 8 pairs of participants knew each other before the study.
Study design:	Within-subjects.
Presence measures:	Bystrom’s questionnaire, 6 items answered by all participants, remaining questions depending on condition.
Performance measure:	<i>Number objects correctly identified, with movement also correctly identified.</i>
Findings:	<ol style="list-style-type: none"> (1) Collaboration had no significant effect on presence, although those who worked with a known partner reported significantly more presence than those who worked with a stranger. (2) Navigation had no significant effect on presence. (3) Head tracking had a significant positive effect on presence for only 1 question (“How realistically did the virtual world move in response to your head motions?”). (4) <i>Collaboration had a significant positive effect on task performance.</i> (5) <i>Navigation had a significant positive effect on task performance with better performance found for those working alone who had more control or working with a partner, than for those working alone with no control.</i> (6) <i>Head tracking had no significant effect on task performance. When considering collaboration, head tracking did have a significant positive effect, with better performance found for participants with head tracking and whose partner had head tracking than for participants working alone with no head tracking.</i>

[Bystrom, 1996] Bystrom, K.-E. and W. Barfield. 1996. “Effects of Participant Movement Affordance on Presence and Performance in Virtual Environments.” *Virtual Reality*, 2(2), 206–216.

Factors:	Movement (seated with chin rest, seated without chin rest, standing).
Computing platform:	SGI Indigo Extreme workstation. In-house software.
Visual display:	GE 610 6 × 8ft rear projection screen. Images displayed using Stereographics Corp. CrystalEyes shutter glasses with 1280 × 512 pixel resolution. Update rate 9 fps. Participants positioned initially so their position subtended a 90° FOV with the projection screen.
Tracking:	Polhemus 3Space Fastrak for head tracking.

Navigation:	Standard mouse attached to a clipboard either handheld, or for chin rest condition placed on table in front of participant.
Object manipulation:	None.
Virtual world:	Virtual cabin with furniture including tables, chairs, a desk, a bookcase, windows with outside scenes, and cupboards. 7 target (A-M) letters positioned around room, mixed with 6 distractor (N-Z) letters. Different versions of room prepared by moving letters. 3 versions for practice trials, 3 versions for experimental trials.
Experimental task:	Locate the target letters. No time limit, focus on accuracy rather than speed.
Participants:	11 participants from university engineering classes and local software community; 7 males, 4 females; age range 21 to 29, mean age 25 years. Participants had normal or corrected-to-normal vision. 6 had previous VE experience, 1 participant more than 5 minutes, 5 participants more than 20 minutes (with different VEs).
Study design:	Within-subjects.
Presence measures:	11-item Bystrom's questionnaire.
Person-related measures:	Age.
Task-related measures:	Rating of task difficulty, rating of enjoyment.
Performance measure:	Search time.
Findings:	<ol style="list-style-type: none"> (1) Movement had no significant effect on presence, but did have a significant effect on rating of realism of response with increased realism reported for seated without chin rest and standing conditions. (2) Movement had no significant effect on ratings of each of realism of depth/volume, ability to reach into VE, task difficulty, or enjoyment. (3) Presence had a significant positive effect on search time only for participants who reported their sense of presence increased when seated. (4) Presence had no significant correlation with age, a significant positive correlation with each of response realism, realism of depth/volume, and a significant negative correlation with reports that presence was affected by standing. (5) <i>Movement had no significant effect on task performance. There was a significant interaction between task complexity and gender, such that males performed better in the more complex task, whereas females fared better in the simple task.</i> (6) <i>Task performance had a significant positive correlation with task difficulty and reports that presence was affected by sitting; but no significant correlation with age, response realism, depth/volume realism, ability to reach into VE, or enjoyment.</i>

[Casanueva, 2001 (1)] Casanueva, J. April 2001. *Presence and Co-Presence in Collaborative Virtual Environments*. M.Sc. Dissertation. University of Cape Town. South Africa.

Factors:	Collaboration (group members had to collaborate to unlock padlocks attached to shapes, no collaboration required).
Computing platform:	SGI Onyx RealityEngine2 with 4 200-MHz R4400, 128 MB RAM. SGI O2 with a 175-MHz R10000 processor, 128 MB RAM. SGI O2 with a 195-MHz R10000 processor, 256 MB RAM. Distributed Interactive Virtual Environment (DIVE) software developed by the Swedish Institute of Computer Science, supporting avatar gravity and collision detection, and University College London Robust Audio Tool (RAT) audio software.
Visual display:	Two 21-inch monitors, one 17-inch monitor.
Audio display:	Headphones.
Navigation:	Using keyboard arrow keys.
Object manipulation:	Pick up and move objects by clicking and releasing mouse button.
Virtual world:	Set of rooms with textured walls, floors, and ceiling that formed a virtual maze. Participants represented by simple "T"-shaped avatars, each participant with a different color (Red, Blue, Green). Participants could not see their own avatar. Audio communications between participants in a group using microphones and headphones.

Training:	Familiarization with VE, including learning how to move through the environment, and pick up objects.
Experimental task:	Move pyramids, cubes, and rectangles into the room marked for each type of shape. Shapes colored to match avatars and could be picked up only by an avatar of the same color. In high-collaboration condition, each shape has an attached padlock of different color, requiring 2 members to collaborate with one clicking to unlock padlock and another to pick up shape within 6 sec. No padlocks were used in the low-collaboration condition. 25 minute time limit.
Participants:	10 groups of 3 students from a 2 nd year psychology course. Members in a group were strangers.
Study design:	Between groups.
Presence measures:	5-item SUS questionnaire, Casanueva's co-presence questionnaire.
Person-related measures:	19-item Witmer-Singer ITQ.
Task-related measures:	14-item collaboration questionnaire.
Findings:	<ol style="list-style-type: none"> (1) Collaboration had a significant positive effect on each of presence, co-presence, and collaboration score. (2) Co-presence had no significant correlation with presence. (3) Collaboration score had a significant correlation with co-presence, a positive correlation in the high collaboration condition and a negative correlation in the low collaboration condition. Collaboration score had no significant correlation with presence. (4) ITQ score had a significant positive correlation with presence, but a significant positive correlation with co-presence only when group collaboration was required for task performance. (5) <i>Collaboration had a significant positive effect on collaboration score.</i>

[Casanueva, 2001 (2)] Casanueva, J. April 2001. *Presence and Co-Presence in Collaborative Virtual Environments*. M.Sc. Dissertation. University of Cape Town. South Africa.

Factors:	Presence manipulation (high presence, low presence).
Computing platform:	SGI Onyx ReaityEngine2 with 128 MB RAM. SGI O2 with a R10000 processor, 256 MB RAM. SGI O2 with a R10000 processor, 128 MB RAM. DIVE and Robust Audio Tool (RAT) software. SGI Indy for recording dialogue in high-presence environment.
Visual display:	Two 21-inch monitors, one 17-inch monitor.
Audio display:	Headphones (and microphones) in high presence condition.
Navigation:	Using keyboard arrow keys.
Object manipulation:	Pick up and move objects by clicking and releasing button on 3-button SGI mouse.
Virtual world:	Ten rooms in an open plan office layout each with a word printed on either the wall (high-presence) or floor (low-presence). Each word with missing letters. These letters scattered in the form of 10 cubes that had the letter written on all sides. Self-representation as colored avatars.
Training:	Practice session in the VE where participant learned how to move through the environment, communicate with each other, and how to pick-up and drop objects.
Experimental task:	Pick up and move cubes to place correct missing letter by each word. Letters could be used in more than 1 word. In low-presence condition, experimenter interrupted participant asking about and then bringing a soft drink. 25 minute time limit.
Participants:	6 groups of 3 students and 1 group of 2 students; 9 males, 11 females.
Study design:	Between groups.
Presence measures:	34-item Witmer-Singer PQ, Casanueva's co-presence questionnaire, total presence (weighted sum of presence and co-presence scores).
Person-related measures:	19-item Witmer-Singer ITQ.
Findings:	<ol style="list-style-type: none"> (1) Presence manipulation had a significant effect on co-presence, and total presence with increased presence reported for the high presence environment; but no significant effect on presence.

- (2) Co-presence had no significant correlation with presence.
- (3) Co-presence and total presence scores had no significant correlation with ITQ scores. Presence had a significant positive relationship with ITQ scores in the high presence environment only.
- (4) *Presence manipulation had no significant effect on ITQ scores.*

[Casanueva, 2001 (3)] Casanueva, J. April 2001. *Presence and Co-Presence in Collaborative Virtual Environments*. M.Sc. Dissertation. University of Cape Town. South Africa. See also Casanueva (2000).

Factors: Avatar realism (realistic human-like, cartoon-like, unrealistic).

Computing platform: SGI Onyx RealityEngine2 with 4 200-MHz R4400 processors, 128 MB RAM. SGI O2 with a 175-MHz R10000 processor, 128 MB RAM. SGI O2 with a 195-MHz R10000 processor, 256 MB RAM. DIVE and RAT software.

Visual display: Two 21-inch monitors, one 17-inch monitor.

Audio display: Headphones (and microphones).

Navigation: Using keyboard arrow keys.

Object manipulation: Pick up and move objects by clicking and releasing mouse button.

Virtual world: Conference room where multiple users meet around a table and have a discussion. Each participant had a book on the table that could be used to view a document. Whiteboard on one wall. Fully textured. Participants could not see their own avatar. Avatars of others had no gestures or facial expressions.

Training: Learning how to move through the environment and pick up objects.

Experimental task: Read a short story by accessing the book on the virtual table and agree on a ranking for the 5 characters in the story, using a grid display and markers on the white board to aid the discussion. 20-minute time limit.

Participants: 6 groups of 3 students from a 2nd year psychology course.

Study design: Between groups.

Presence measures: 5-item SUS questionnaire, Casanueva's co-presence questionnaire.

Person-related measures: 19-item Witmer-Singer ITQ.

Findings: (1) Avatar realism had a significant effect on co-presence, with participants seeing realistic avatars reporting more presence than those seeing unrealistic avatars.
 (2) Co-presence had no significant correlation with presence.
 (3) ITQ score had a significant positive correlation with presence, but no significant relationship with co-presence.

[Casanueva, 2001 (4)] Casanueva, J. April 2001. *Presence and Co-Presence in Collaborative Virtual Environments*. M.Sc. Dissertation. University of Cape Town. South Africa. See also Casanueva (2000).

Factors: Avatar functionality (gestures, gestures and facial expressions, no functionality).

Computing platform: Experimental task: As above in [Casanueva, 2001 (3)] except avatars had gestures (waving, raising arms, joy and sad gestures, head movements such as yes, no, and perhaps, walking) and facial expressions (sad, happy, neutral, surprised, disgusted, angry, furious).

Participants: 10 groups of 3 students from a 2nd year psychology course.

Study design: Between groups.

Presence measures: 5-item SUS questionnaire, Casanueva's co-presence questionnaire.

Person-related measures: 19-item Witmer-Singer ITQ.

Findings: (1) Avatar functionality had a significant effect on co-presence, with those seeing avatars with gestures and facial expression reporting more co-presence than those seeing avatars with no functionality.
 (2) Co-presence had no significant correlation with presence.
 (3) ITQ score had a significant positive correlation with presence, but no significant relationship with co-presence.

[Cho, 2003] Cho, D., J. Park, G.J. Kim, S. Hong, S. Han, and S. Lee. 2003. "The Dichotomy of Presence Elements: The Where and How." In *Proc. IEEE Virtual Reality 2003 Conference*, 22–26 March, Los Angeles, CA,. 273–274.

Factors: Stereopsis (stereo, mono), navigation (fixed navigation, view at fixed location), level of detail (moving/stationary fish), level of detail (no deformation, with deformation), geometry (high/low polygon count), texture (present, absent).

Visual display: 50-inch projection screen.

Navigation: None.

Object manipulation: None.

Virtual world: Virtual undersea world.

Experimental task: View each of 32 virtual worlds for 90 sec.

Study design: Within-subject.

Presence measures: Cho's questionnaire on realism and presence.

Findings: (1) All conditions had a significant positive effect on presence.
(2) The interaction of geometry and level of detail (deformation), of texture and level of detail (moving/stationary fish), and of texture and navigation all had a significant positive effect on presence.

[Commarford, 2001] Commarford, P.M., M.J. Singer, and J.P. King. 2001. *Presence in Distributed Virtual Environments*. U.S. Army Research Institute for the Behavioral and Social Sciences. Orlando, FL.

Computing platform: SGI Onyx and RealityEngine2 with 8 200 MHz, 256 MB RAM, R4400 processors. In-house software.

Visual display: Stereoscopic, color Virtual Reality VR8 HMDs.

Audio display: Stereo headphones.

Tracking: Head, each ankle, right wrist and elbow, and harness sensors tracked by an Ascension Technologies MotionStar (wired version) with an extended range transmitter.

Navigation: Walking-in-place on a platform with barrier.

Virtual world: Several scenarios using 10-room virtual buildings laid out along a single corridor approximately 4m wide with one 90° turn, either to the right or left. Corridors all scaled to 70m in length, with the turn at 20, 25, or 30 m. Rooms varied between 5 × 10m and 15 × 10m in size, with office furniture, home furnishings, warehouse shelving, bookcases, and desks placed in realistic arrangements. The buildings were designed to represent normal offices, a school, a department store, a library, a warehouse, and single story homes. The scenarios ranged from simple to complex with varying numbers of neutral hostages, opposing forces, and gas canisters. Canisters had 1 or 3 possible states: no gas and not armed, gas and not armed, gas and armed. Sound cues included voice communications, collision noises, door opening, grenade explosions, and gunfire.

Training: Individual and teamed with an automated partner for 4-hour training session on VE equipment and tasks, in which exposed to VE 3 to 4 times. Started with walking through a simple VE, final training included equipment operation and team tasks partnered with an automated agent.

Experimental task: Paired with partner to complete a series of 8 VE mission rehearsals. Each mission involved searching for and disarming gas canisters.

Participants: 64 students from the University of Central Florida, or co-op students from universities working at the Canadian Defence and Civil Institute of Environmental Medicine. Normal to corrected-to-normal vision.

Person-related measures: 29-item ITQ Version 2.0.

- Findings:
- (1) PQ scores taken after final training were significantly different to PQ scores after initial, simple movement training for PQ Total, and PQ Natural, Involved/Control, Auditory, and Haptics subscales with higher presence reported after final training.
 - (2) PQ scores taken after the first team mission were significantly different to PQ scores after final training for PQ Total and PQ Involved/Control subscale, with higher presence reported after final training.
 - (3) PQ scores taken after the last team mission were significantly different to PQ scores after the first mission for PQ Total and PQ Involved/Control subscale, with increased presence reported after the final mission.
 - (4) When measured after initial training, ITQ Focus subscale had a significant positive correlation with PQ Total, and PQ Involved/Control and PQ Resolution subscales.
 - (5) When measured after final training, ITQ scores had no significant correlation with PQ scores.
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[Darken, 1999 (2)] Darken, R.P., D. Bernatovich, J.P. Lawson, and B. Peterson. 1999. "Quantitative Measures of Presence in Virtual Environments: The Roles of Attention and Spatial Comprehension." *CyberPsychology & Behavior*, 2(4), 337–347.

- Factors: Audio cues (semantic and spatial information, semantic information, spatial information, no cues).
- Visual display: 3-screen semi-circular mini-Cave.
- Navigation: Joystick for viewpoint control only.
- Object manipulation: None.
- Virtual world: Participant given a guided car tour of a town. Semantic audio cues provided information such as "This Mobil Station has a car wash and was built 3 years ago," spatial audio cues provided information such as "This Mobil Station is on the north side of town adjacent to the park."
- Experimental task: Observe the virtual world while on an automated car tour.
- Participants: 40 participants; 33 males, 7 females; mean age 32.5 years.
- Study design: Between-subjects.
- Presence measures: 32-item Witmer-Singer PQ Version 2.0.
- Performance measures: Spatial knowledge acquisition: map building and pointing task scores, number correct landmarks selected.
- Findings:
- (1) Audio cues had a significant positive effect on PQ scores, with both semantic and spatial information cues yielding more presence than no audio cues.
 - (2) Map building and landmark identification scores had no significant correlation with PQ scores.
 - (3) *Audio cues had no significant effect on map building scores or pointing task scores, but a significant effect on landmark selection with both the spatial and spatial with semantics cues giving better performance.*
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[Deisinger, 2001] Deisinger, J., C. Cruz-Neira, O. Riedel, and J. Symanzik. 2001. *The Effect of Different Viewing Devices for the Sense of Presence and Immersion in Virtual Environments, A Comparison of Stereoprojections Based on Monitors, HMDs, and Screens*. Available at <http://vr.iao.fhg.de/papers/hci/hcifull.htm>.

- Factors: Visual display (HMD, 21-inch monitor with shutter glasses, 4-wall screen projection system).
- Visual display: Stereoscopic HMD with 240 × 120 pixel resolution per eye, 21-inch monitor with shutter glasses driven in a 1280 × 1024 resolution, or a 4-wall cube screen-based projection system with edge size of 144 inches and 1024 × 768 pixel resolution per wall.
- Training: Each subject practiced to "asymptote" before actual trials began.

Experimental task: Identify 15 boxes in their correct order. 3 to 20 minutes depending on display device. 3 trials

Participants: 18 participants; 14 males, 4 females; mean age 29 years. 12 participants had no prior experience with virtual environments. Distribution of visual aids 50%.

Study design: Within-subject.

Presence measures: 1 item on immersion.

Findings: (1) Visual display had a significant effect on presence, with greater presence reported for 4-wall screen projection system.
(2) Visual display also had a significant interaction with the order in which each device was used.

[Dinh, 1999] Dinh, H.Q., N. Walker, L.F. Hodges, C. Song, and A. Kobayashi. 1999. "Evaluating the Importance of Multi-sensory Input on Memory and the Sense of Presence in Virtual Environments." In *Proc. IEEE Virtual Reality Conference*, March 13–17, Houston, TX. Los Alamitos, CA: IEEE Computer Society. 222–228.

Factors: Tactile cues (present, absent), olfactory cues (present, absent), audio cues (present, absent), visual detail (high detail, low detail).

Computing platform: Modeled using Alias Wavefront. Rendered by in-house software built using Georgia Institute of Technology's SVE toolkit.

Visual display: HMD with frame rate 20 fps.

Tactile display: Tactile cues, when present, were a real fan to produce effect of virtual fan and heat lamp used to simulate standing in sunshine.

Olfactory display: Olfactory cue was the scent of coffee delivered using a small oxygen mask connected to: (1) a canister of coffee grounds and a small pump, and (2) fresh air source and additional pump.

Auditory display: Delivered via headphones: sound of a fan, a toilet flushing, a copier machine, and city noise; volumes (usually on/off) varied according to participant's location.

Tracking: Head tracking.

Navigation: None, participant positioned at 2 locations within each room in the VE.

Object manipulation: None.

Virtual world: Corporate office suite including a reception area, hallway, bathroom, small office, copier room, larger office, and balcony. All spaces appropriately furnished. Texture mapping for pictures, furniture material, and an outdoor city view. For high visual detail, local light sources were simulated and high resolution text maps used; for low visual detail used only ambient lighting and reduced texture resolutions to 25% previous value.

Training: Training room containing objects such as books on the floor, a table, a vase, and a speaker. Training task to find each of 5 specific objectives.

Experimental task: Evaluate the effectiveness of a VE system for use by real estate brokers. Virtual tour took approximately 5 minutes.

Participants: 322 undergraduate students with no or 1-time experience in a VE.

Study design: Between-subjects.

Presence measures: Dinh's questionnaire.

Performance measures: *Memory test with 4 items on spatial layout questionnaire, 5 items on object location.*

Findings: (1) Audio cues and tactile cues had a significant positive effect on presence.
(2) Visual detail and olfactory cues had no significant effect on presence.
(3) *Audio, tactile, visual, and olfactory cues had no significant effect on spatial layout memory. Tactile and olfactory cues had a significant positive effect on object location memory, audio and visual cues had no significant effect.*

[Hendrix, 1996a (1)] Hendrix, C. and W. Barfield. 1996. "Presence within Virtual Environments as a Function of Visual Display Parameters." *Presence*, 5(3), 274–289.

Factors: Head tracking (present, absent).
Computing platform: SGI Extreme workstation.
Visual display: GE-610 6 × 8ft rear projection screen, stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses. Images generated with 1280 × 512 pixel resolution, standard conditions were GFOV 50°. (Shutter glasses also worn in monoscopic condition with disparity set to zero.) Eyepoint elevation 110 cm. Subject seated/standing so position subtended a 90° FOV.
Tracking: Polhemus 3Space Fastrak for head tracking.
Navigation: Standard mouse placed on table in front of subject.
Object manipulation: None.
Virtual worlds: 10 × 10m virtual room with checkerboard patterned floor and several familiar objects such as tables and chairs, a bookshelf, a soda machine, a photocopier machine, and paintings.
Experimental task: Navigate around room to become familiar with the environments in order to answer questionnaire previously made available. No time limit.
Participants: 12 university students; 6 male, 6 female; mean age 27 years. Normal or corrected-to-normal visual acuity. Same participants used in [Hendrix, 1996a (2), (3)].
Study design: Within-subjects.
Presence measures: 4-item Hendrix's questionnaire, including overall presence rating, 1 item on sense of "being there," 1 item on realism, 1 item on responsiveness.
Findings: (1) Head tracking had a significant positive effect on each measure of presence.
(2) Head tracking had a significant positive effect on each of realism and responsiveness.
(3) Realism of interaction and response each had a significant positive correlation with presence rating and sense of "being there."

[Hendrix, 1996a (2)] Hendrix, C. and W. Barfield. 1996. "Presence within Virtual Environments as a Function of Visual Display Parameters." *Presence*, 5(3), 274–289.

Factors: Stereopsis (present, absent).
Computing platform...Study design. As above.
Presence measures: 5-item Hendrix's questionnaire, including overall presence rating, 1 item on sense of "being there," 1 item on realism of response, 1 item on realism of depth/volume, 1 item an ability to reach into VE.
Findings: (1) Stereopsis had a significant positive effect on each measure of presence.
(2) Stereopsis had a significant positive effect on each of rating of realism of depth/volume and ability to reach into VE; and no significant effect on rating of realism of response.
(3) Realism of response, realism of depth/volume, and ability to reach into VE each had a significant positive relationship with presence rating and sense of "being there."

[Hendrix, 1996a (3)] Hendrix, C. and W. Barfield. 1996. "Presence within Virtual Environments as a Function of Visual Display Parameters." *Presence*, 5(3), 274–289.

Factors: Geometric FOV (10°, 50°, 90°).
Computing platform...Study design. As above, except used 3 virtual worlds.
Presence measures: 6-item Hendrix's questionnaire, including overall rating, 1 item on sense of "being there." Remainder consisted of 1 item on realism of virtual world, 1 item on object

compression/magnification, 1 item on narrowness/width, 1 item on proportional correctness.

Findings:

- (1) GFOV had a significant effect on each measure of presence, realism, and proportional correctness with reported presence higher for GFOV 50° than 10°, and for GFOV 90° than 10°.
- (2) GFOV had no significant effect on each of perceived object compression/magnification and narrowness/width.
- (3) Realism and perception of proportionally correct each had a significant positive correlation with presence rating and sense of “being there;” perception of compression/magnification and view each had no significant correlation with either measure of presence.

[Hendrix, 1996b (1)] Hendrix, C. and W. Barfield. 1996. “The Sense of Presence within Auditory Virtual Environments.” *Presence*, 5(3), 290–301.

Factors: Audio cues (spatialized sound, no sound).

Computing platform: SGI Indigo Extreme workstation. Crystal River Engineering Beachtron audio spatialized card in 386 PC.

Visual display: GE-610 6 × 8ft rear projection screen, stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses. Images generated with 1280 × 512 pixel resolution. Subject seated to achieve 90°H FOV, 50° GFOV.

Audio display: Yamaha YH-1 orthodynamic headphones, with radio signal delivered via a Realistic receiver/amplifier. Soda machine sounds obtained using an Ensoniq digital sound sampler. Sounds uncorrelated with actions in VE.

Tracking...Experimental task: As in [Hendrix, 1996a (1)] above.

Participants: 16 university students; 14 males, 2 females; mean age 29.9 years. Normal or correct-to-normal visual acuity. Normal binaural heading. 4 participants had previously participated in presence-related studies.

Study design: Within-subjects.

Presence measures: 3-item Hendrix’s questionnaire, including overall rating, 1 item on sense of “being there,” 1 item on realism of virtual world.

Findings:

- (1) Audio cues had a significant effect on each measure of presence, with increased presence reported for spatialized sound.
- (2) Realism had a significant positive effect on overall presence rating and sense of “being there.”

[Hendrix, 1996b (2)] Hendrix, C. and W. Barfield. 1996. “The Sense of Presence within Auditory Virtual Environments.” *Presence*, 5(3), 290–301.

Factors: Audio cues (spatialized sound, non-spatialized sound).

Computing platform...Study design: As in [Hendrix, 1996b (1)] above.

Presence measures: 5-item Hendrix’s questionnaire, including overall rating, 1 item on sense of “being there,” 1 item on realism of virtual world, 1 item on realism of interaction with sound sources, 1 item on emanation of sound from specific locations.

Findings:

- (1) Audio cues had a significant positive effect on each measure of presence, with increased presence reported for spatialized sound.
- (2) Realism in appearance, interaction, localization each had a significant positive effect on overall presence rating and sense of “being there.”

[Hoffman, 1999b] Hoffman, H.G, A. Hollander, K. Schroder, S. Rousseau, and T. Furness III. 1999. *Physically Touching, and Tasting Virtual Objects Enhances the Realism of Virtual Experiences*. HITL, University of Washington, WA. Available at <http://www.hitl.washington.edu/publications/r-99-7/>.

Factors: Olfactory cues (biting candy bar, imagining biting candy bar).
 Computing platform: Division Ltd. ProVision 100 system.
 Visual display: Division Ltd. dVisor HMD with FOV 40° V × 105° H, 40° overlap.
 Tracking: Polhemus sensors attached to fingerless bicycle glove and to real candy bar.
 Navigation: None.
 Object manipulation: Using 3D wand.
 Virtual world: Division Ltd.'s KitchenWorld demo with virtual candy bar. Self-representation as virtual hand.
 Experimental task: Examine kitchen for 1 minute. Then close eyes while experimenter tears off part of the wrapper and places candy bar in participant's hand. Open eyes and smell candy bar. In biting condition, take a bite out of the candy bar; in imagine condition only imagine taking a bite.
 Participants: 21 university students.
 Presence measures: Hoffmam's questionnaire.
 Findings: Olfactory cues had a significant positive effect on presence.

[Hoffman, 1998b] Hoffman, H.G., J. Groen, J. Prothero, and M.J. Wells. 1998b. "Virtual Chess: Meaning Enhances Users' Sense of Presence in Virtual Environments." *Inter. Journal of Human-Computer Interaction*, 10(3), 251–263.

Factors: Meaning (meaningful chess position, meaningless chess position), task expertise (non-chess player, weak player, strong player, tournament-level player).
 Computing platform: Provision 100 reality engine.
 Visual display: Division dVisor HMD with FOV 40° V × 105° H, 40° overlap.
 Tracking: Polhemus 6 DOF head and mouse tracking.
 Navigation: Only by moving head to change coordinates and get a closer view of chessboard.
 Object manipulation: Using 3DOF mouse.
 Virtual world: Virtual chess board on a wooden floor. Tartakower and DuMont's 16 middle game positions were used as meaningful stimuli, the chess pieces from each middle game were rearranged in a random manner to create 16 meaningless positions.
 Training: Familiarization with VEs and interface devices by 5 minutes playing Division's Shark game.
 Experimental task: Each participant presented with 16 chess positions, each labeled meaningful or meaningless, and told to memorize the positions. 1 minute for each set of positions.
 Participants: 33 participants from a university and a city chess club.
 Study design: Within-subjects (meaning), between-subjects (chess expertise).
 Presence measures: 4-item Hendrix's questionnaire.
 Person-related measures: Chess-playing ability.
 Task-related measures: *Memory accuracy on identifying 16 studied chessboard positions (8 meaningful and 8 meaningless) among 32 presented positions.*
 Findings: (1) Meaningfulness had a significant positive effect on presence.
 (2) Task expertise had no significant main effect on presence. A significant interaction was found with meaningfulness such that non-chess players showed no significant effect for meaningfulness, but all other classes of players showed a significant positive effect of meaningfulness on presence.
 (3) *Each of meaningfulness and task expertise had a significant positive effect on memory accuracy. A significant interaction between these was found, such that tournament players were significantly more accurate on meaningful positions, whereas no significant difference was found for all other classes of task expertise.*

[Hoffman, 1996] Hoffman, H., J. Groen, S. Rousseau, A. Hollander, W. Winn, M. Wells, and T. Furness. 1996. *Tactile Augmentation: Enhancing Presence in Virtual Reality with Tactile Feedback from Real Objects*. Technical Report 96-1. HITL Lab, University of Washington, WA.

Factors:	Haptic cues (mixed reality with physical objects, virtual objects only).
Computing platform:	Division Ltd. ProVision 100 system.
Visual display:	Division Ltd. dVisor HMD with FOV 40° V × 105° H, 40° overlap.
Tracking:	Position sensor attached to hand.
Object manipulation:	3DOF mouse with trigger button used to ‘pick-up’ object.
Virtual world:	Included models of 8 real items (e.g., butter knife) with texture mapping. Self-representation as virtual hand.
Experimental task:	Observe some objects, observe and touch other objects.
Participants:	14 university students.
Study design:	Within-subjects.
Presence measures:	5-item Hoffman’s questionnaire.
Findings:	Haptic cues had a significant positive effect on presence.

[Huie, 2003] Huie, O.P., C. Youngblut, and B.J. Buck. 2003. “The Relationship Between Presence and Task Performance in Virtual Environments: Boeing Study II.” Under preparation. Institute for Defense Analyses. Alexandria, VA.

Factors:	Training type (extensive interactive training, simple training).
Computing platform:	Dell Optiplex GX 260 workstation.
Visual display:	19-inch monitor.
Audio display:	Headphones.
Navigation:	Using standard mouse.
Object manipulation:	Using standard mouse.
Virtual world:	VRML scene depicting Intel Ice Detection System and corresponding scenarios.
Experimental task:	Self-paced training in maintenance of the Intel Ice Detection System using either extensive interaction with a high level of detail, or simple mouse click to move between procedural steps. For training transfer test, troubleshoot a problem and perform a repair on a physical mock-up of the Ice Detection System.
Participants:	40 Boeing volunteers; 39 males, 1 female; age range 23 to 63, mean age 44 years.
Study Design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 1.0, 6-item SUS Questionnaire.
Person-related measures:	29-item ITQ Version 1.0, visualization aptitude using Ekstrom’s Paper Folding test, computer experience, game playing.
Task-related measures:	Training time.
Performance measures:	Paper-and-pencil knowledge test, time to complete training transfer task on physical mock-up, count of important errors while completing training transfer test.
Findings:	<ol style="list-style-type: none"> (1) Training type had no significant effect on presence. (2) PQ Total scores had a significant negative correlation with transfer test time, PQ Interface subscale scores had a significant positive correlation with knowledge test scores. (3) SUS score had a significant negative correlation with knowledge test scores only. (4) SUS scores showed a significant positive correlation with PQ Total, Involved/Control, Natural, Interface subscale scores. (5) PQ and SUS scores showed no significant correlation with ITQ Total or any subscales. (6) Visualization aptitude and computer experience had no significant correlation with presence. Game playing had a significant negative correlation with PQ Interface subscale score, none with SUS scores. (7) <i>Training type had a significant positive effect on training time and transfer test time only.</i>

[Hullfish, 1996] Hullfish, K. 1996. *Virtual Reality Monitoring: How Real is Virtual Reality?* M.Sc. Dissertation. Human Interface Technology Laboratory, University of Washington.

Factors:	Environment type (real, virtual, imagined).
Computing platform:	Division Ltd. Provision 100 system with dVise software. Geometry created using 3Dstudio and Macromodel. Lighting simulated using directional and ambient light, metallic surfaces simulated.
Visual display:	Stereoscopic Division Ltd. dVisor HMD with FOV 105°H × 41°V. Subject's height was simulated. Experimental area curtained off.
Navigation:	Using single button on 3D joystick.
Object manipulation:	Pointing to objects using virtual hand.
(Virtual) world:	Each world had a 12 × 12ft chessboard in the middle of the floor, and four 14 × 14 × 14 inch identical objects (cubes, half cylinders, 3D "T"s, or 3D triangles) of different colors (red, purple, yellow, and blue) arranged in a pattern on the chessboard. Four sets of 8 worlds were developed, each arrangement was 1 of 8 distinct, global shapes (e.g., curve, trapezoid). 4 sets of 8 worlds were developed, experienced in either virtual world, real, or imagined condition. (Imagined was the same as the real condition, except objects were not present and had to be imagined based on written instructions.) In the virtual world, ceiling and stone walls were texture mapped with photographs from real environment, details included electrical outlets, conduits, and switches. Self-representation as virtual hand.
Training:	Play Division Ltd. Shark World game to become familiar with the equipment and navigational controls. Two practice trials in each type of environment.
Experimental task:	In the study phase, for each of 24 worlds, memorize (and later report) the spatial configuration of the 4 objects and the position of this global shape on the chessboard while navigating a pre-defined path and pointing to each object as they passed it. Then play in a Chemistry World VE for 15 minutes. In the test phase, for each of 32 worlds presented on a PC, determine whether that world had been seen previously and, if so, in what type of environment.
Participants:	16 participants from the University of Washington community; 6 males and 10 females; age range 20 to 38 years. No experience in VE technology.
Study design:	Within-subjects.
Presence measures:	Virtual Reality Monitoring, Memory Characteristic Questionnaire (MCQ).
Task-related measures:	<i>Item on MCQ concerned with cognitive effort.</i>
Performance measures:	<i>Items on MCQ concerned with rating memories of real, virtual, and imagined environments.</i>
Findings:	<ol style="list-style-type: none">(1) Environment type had a significant effect on each of the "sense of being there" and "being surrounded by objects" with higher ratings reported for the real environments than for the virtual or imagined environments, which were not significantly different.(2) Environment type had no significant effect on the "sense of visiting rather than seeing an environment," on "remembering being a spectator rather than a participant," or "awareness of my body."(3) <i>For old/new recognition, environment type had no significant effect on frequency with which worlds were misrecognized as new, participants missed new worlds significantly more than frequently than any other worlds from another origin, and were as likely to miss virtual and imagined worlds than to correctly identify them as old.</i>(4) <i>For correct identification of origin, environment type had a significant effect with virtual worlds identified correctly less frequently than real, imagined, or new worlds, these worlds very more frequently assigned as real rather than imagined or new.</i>

- (5) *Environment type had a significant effect on cognitive effort, with experience in imagined worlds being rated as more difficult, virtual less difficult, real easiest. Real and virtual memories were rated as the most similar.*

[Insko, 2001 (2)] Insko, B.E. 2001. *Passive Haptics Significantly Enhances Virtual Environments*. Ph.D. Dissertation. University of North Carolina at Chapel Hill.

Factors:	Haptic cues (practice in mixed-reality maze, practice in unaugmented virtual maze).
Computing platform:	SGI Onyx2, with 1 Infinite Reality2 Engine with 4 R12000 processors, 4 raster managers, and 64 MB texture memory. Mean system lag 110 ms. In-house software.
Visual display:	Virtual Research V8 HMD, with FOV 60° diagonal at 100% stereo overlap, 640 × 480 tri-color pixel resolution per eye. Update rate generally 20–30Hz.
Audio display:	Real radio placed in location of virtual radio, and used to give instructions to participants. A hand colliding with a virtual object caused a sound (different sounds for right and left hand (such a collision also changed block color to red) in the unaugmented virtual maze condition only.
Haptic display:	Solid objects made of styrofoam and cardboard used to define maze path.
Tracking:	Head tracking using UNC Tech Hi-Ball, allowing movement in 4 × 10m area. Hand and knee tracking using Polhemus FastTraks.
Navigation:	Actual walking.
Object manipulation:	Joystick with push buttons.
Virtual world:	Room furnished with rectangular colored objects forming a single-path maze, where path consisted of 11 turns. Patterned textures used on floor, walls, and ceiling.
Training:	None.
Experimental task:	Complete 3 clockwise laps through the environment, touching all objects, while trying to get a sense of the layout. Then, while blindfolded, complete 1 lap in equivalent real world maze, this time without touching objects.
Design:	Between-subject.
Participants:	33 undergraduate computer science students; 17 males, 16 females; age range 19 to 23 years. Participants were able to use stereopsis for depth perception; were not color blind; were ambulatory and in their usual state of good physical fitness; had no history of epilepsy, seizures, or strong susceptibility to motion sickness; and were comfortable with the VR system.
Study design:	Between-subjects.
Presence measures:	Witmer-Singer PQ.
Person-related measures:	Guilford-Zimmerman Spatial Orientation Test, gender.
Performance measures:	<i>Cognitive sketch maps, height estimation of 4 objects, estimated distance between two objects. In real environment: time to complete lap, number of object collisions, number of wrong turns.</i>
Finding:	(1) Haptic cues had no significant effect on presence. (2) Gender had no significant effect on presence. (3) Spatial orientation score had no significant effect on presence. (4) <i>Haptic cues had a significant positive effect on completion time, number of collisions, distance estimation accuracy, and number of attempted wrong turns (with improved performance when haptic cues were present).</i> (5) <i>Haptic cues had no significant effect on sketch map accuracy and height estimation accuracy.</i>

[Johnson, 1995] Johnson, D.M. and D.C. Wightman. November 1995. *Using Virtual Environments for Terrain Familiarization; Validation*. Research Report 1686. U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors:	Detail level (Hanchey Army Heliport, portion of Arizona).
Computing platform:	Simulator Training Research Advanced Testbed for Aviation (STRATA).
Visual display:	Stereoscopic, fiber-optic helmet-mounted display with FOV 127°H × 66°V, resolution 5 arcminutes for background and 1.5 arcminutes for high-resolution insets in the center of the visual field, luminance >35 footlamberts, contrast ratio 50:1. Helmet individually fitted and optically aligned for each participant. Update rate 60Hz. Participant seated in an AH-64A Apache helicopter pilot cockpit simulator with all flight instruments/controls/motion displays switched off or covered by a black blanket. Black curtain surrounded cockpit area.
Audio display:	Intercom system.
Tracking:	Infrared head tracking system.
Navigation:	Joysticks attached to right and left arms of seat to control up/down or left/right movement, with button to reposition participant to a preset VE location.
Object manipulation:	None.
Virtual world:	(1) Hanchey Army Heliport (HAH) at Fort Rucker. 'T'-shaped area with dimensions approx. 0.5 × 0.7 miles, including all features relevant to flight training missions, with structure colors matched from photos or videotape, signs and logos texture mapped onto buildings. Area included 19 helipads with parking ramps, taxi lanes, and overrun areas; 30 (semi) permanent buildings, control tower, beacon tower, antenna pole, 3 windsocks, 4 fuel tanks; and miscellaneous objects such as fire trucks, water tank, satellite receiver dish. One of each of 4 types of helicopter cycled continuously through their respective traffic patterns. (2) Portion of Arizona taken from STRADA's Arizona database. Approx. 10 × 10 miles. Area centered east of Phoenix and included part of Mesa. Contained urban, residential, and desert terrain; with appropriate types and densities of buildings, businesses, churches, houses, towers, playgrounds cars, roads, parking lots, signs, stream, and vegetation; no moving models. Both virtual worlds had a large, red 3D cursor in lower center field of view pointing to magnetic north. Participants were represented in each virtual world by a black 2.5 × 3 foot virtual carpet they could see underneath their seat and feet when they looked down.
Training:	Familiarization with cockpit, helmet-mounted display, and 3-minutes practice using joysticks.
Experimental task:	Self-guided exploration of either HAH or Arizona VE. Three 30-minute sessions.
Participants:	12 soldiers from aviation units at Fort Rucker; males 10, females 2; age range 23 to 20, mean age 28.3 years. None had previously visited the HAH.
Presence measures:	32-item Witmer-Singer PQ Version 2.0.
Findings:	(1) Level of detail had no significant effect on presence.

[JSC, 2000] JSC Technology Applications Programme. February 2000. *JTAP Project 305 Human Factors Aspects of Virtual Design Environments in Education*: Project Report. Advanced VR Research Center, Loughborough University, UK.

Computing platform:	Division Inc. ProVision100 system, with dVS Version 3.1.2.
Visual display:	Division Inc. HMD.
Tracking:	Polhemus Fastrak for head tracking.
Navigation:	Using Division Inc. 3D mouse.
Object manipulation:	Using Division Inc. 3D mouse.
Virtual world:	Tool box.
Experimental task:	Perform a series of create, link, and animation operations according to a predefined task list to develop virtual scenes.

Participants: 18 participants.

Presence measures: 10-item presence section on VRUSE questionnaire, also includes 11 items related to simulation fidelity.

Findings: (1) Quality of simulation had a significant positive correlation with the sense of immersion, the sense of “being present,” and overall feeling of being present in the VE.
 (2) Fidelity of the VE had a significant positive correlation with sense of being immersed.
 (3) A belief that the quality of the simulation improved performance had a significant positive correlation with the sense of presence and the overall feeling of ‘being present’ in the VE.
 (4) Accuracy of simulation had a significant positive correlation with both the sense of immersion and the sense of presence.

[Knerr, 1994 (1)] Knerr, B.W., S.L. Goldberg, D.R. Lampton, B.G. Witmer, J.P. Bliss, J.M. Moshell, and B.S. Blau. 1994. “Research in the Use of Virtual Environment Technology to Train Dismounted Soldiers.” *Journal of Interactive Instruction Development*, Spring, 9–20.

Factors: Navigation (joystick, spaceball).

Computing platform: Two 486/50 MHz PCs with Intel DVI display boards. Sense8 Corp. WorldToolkit.

Visual display: Virtual Research Corp. Flight Helmet.

Tracking: Polhemus Isotrack for head tracking.

Navigation: Gravis joystick or Spaceball Tech Spaceball.

Virtual world: Virtual Environment Performance Assessment Battery (VEPAB) world.

Experimental task: Complete 20 tasks from VEPAB battery, ranging from vision to reaction time tests.

Participants: 24 participants, primarily college students. Normal or corrected-to-normal vision.

Presence measures: Witmer-Singer PQ.

Person-related measures: Witmer-Singer ITQ.

Task-related measures: Kennedy SSQ.

Performance measures: Completion time for locomotion task, object manipulation task, tasking tasks.

Findings: (1) ITQ score had no significant correlation with PQ score.
 (2) SSQ total score had a significant negative correlation with PQ score.
 (3) Type navigation had a significant effect on completion time for locomotion and object manipulation tasks, with quicker time found for joystick, but no significant effect on completion time for tracking tasks.

[Lampton, 2001a] Lampton, D.R., D.P. McDonald, M.E. Rodriguez, J.E. Cotton, C.S. Morris, J. Parsons, and G. Martin. March 2001. *Instructional Strategies for Training Teams in Virtual Environments*. Technical Report 1110. U.S. Army Research Institute for the Behavioral and Social Sciences. Alexandria, VA. See also Lampton (2001b).

Factors: Instructional strategy (demonstration, coaching, replay, no feedback).

Computing platform: SGI Onyx RE2 with 8 processors/3 pipes, SGI Onyx RE2 with 4 processors/1 pipe, SGI Indigo High Impact, SGI Indy, Dell Pentium 90, Dell 486. Audio capture and playback using a Dell Optiplex 560 PC running Windows 95 with Sound Blaster AWE64.

Visual display: Two VR4 HMDs.

Audio display: HMD headphones.

Tracking: Two 6-tracker Ascension Technologies MotionStars for tracking body position, gaze, and locomotion.

Navigation: Walking-in-place with participant standing within a circular barrier.

Object manipulation: Palm grip of a Gravis Blackhawk joystick with thumb switch to cycle through an array of configurable hand held items. Index finger trigger.

Virtual world:	10 rooms positioned along a hallway containing one 90° turn. Six floor plans, differing in directions in which hallways branch and location of rooms. Seventh floor plan with a multistory structure. Gas canisters. Avatars depict a person in HAZMAT gear, incorporates 45 DOF beads for realistic deflection of limbs and torso, raising and lowering legs synchronized to participant locomotion, articulating right arm synchronized to participant's arm movement. VE supports action-after critique system that provides a playback mechanism. Sound cues: gun shots, door opening/closing, collision sounds, and communications with team members.
Training:	Two virtual worlds for practice in walking in a VE and practice using the manual control device to select and use equipment. First consists of a large room and a connecting series of corridors. Second contains examples of various types of equipment, friendlies, enemies, and neutrals that can be encountered during missions, participant practice using the pistol and necessary equipment. Each training mission took 8 minutes. No feedback group performed 2 trials in second practice environment. Demonstration group watched replay of mission performed by experienced team, followed by practice session. Replay group performed one practice mission followed by watching replay of their performance. Coaching group were provided prompts or suggestions as team conducted 2 practice missions.
Experimental task:	Working in 2-man teams, search for canisters containing hazardous gas and, if necessary, deactivate canisters. Computer-generated enemy and innocent bystanders moved through hallways and rooms. Air supply limited to 8 minutes. Rules define order in which rooms are searched, team formation for room entry, actions on contact with enemy and innocent bystanders, assign areas of responsibility within a room, and how/what to report on the radio network.
Participants:	81 participants recruited from local colleges; approx. 45% male, 55% female; age ranged 17 to 52, mean age 21 years. Presence data collected from only 40 participants.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 2.0.
Person-related measures:	29-item ITQ Version 2.0.
Performance measures:	<i>Task completion time.</i>
Findings:	<p>(1) ITQ total score had no significant correlation with PQ Total.</p> <p>(2) Compared with previous ARI VEs studied, the increased task complexity, presence of a teammate, and use of sound effect of this VE did not result in a higher mean PQ score.</p> <p>(3) <i>Instructional strategy had no significant effect on task completion time.</i></p>

[Larsson, 2001] Larsson, P., D. Västfjäll, and M. Kleiner. 2001. "The Actor-Observer Effect in Virtual Reality Presentations." *CyberPsychology & Behavior*, 4(2), 239–246.

Factors:	Interaction (actor, observer).
Computing platform:	PIII-600 NT workstation with ELSA Gloria XXL graphics board. Model created using CATT-Acoustic and transferred to EON Studio. Auditory scene rendered using Lake Technologies Aniscape software, CP4 hardware.
Visual display:	For actor condition, a Sony Glasstron HMD in stereoscopic mode. For observer condition, monoscopic screen projector. All participants seated approx. 2m from projection screen.
Audio display:	For actor condition, Beyerdynamic DT990 headphones. For observer condition, Sennheiser HD 414 headphones.
Tracking:	For actor condition, Polhemus Fastrack for head tracking.
Navigation:	Logitech Wingman regular joystick.
Object manipulation:	None.

Virtual world:	Model of Orgryte Nya Kyrka church in Gothenburg, Sweden. Some textures and two avatars. Auditory source was “Swanee River” performed by a female singer and visually represented as female avatar moving along a predetermined path in the church. Visual and auditory stimuli synchronized between female avatar and actor.
Training:	Instruction on use of joystick and HMD.
Experimental task:	For actor condition, count the number of windows in the church and find 4 different balls positioned in the church and then return to starting position. A sentence appears when move close to a ball, with the color of the text the same as the color of the next ball to be found. Task took about 10 minutes. Also requested to remember each piece of text (sentence
Participants:	32 undergraduate or graduate students (16 actors, 16 observers); 23 males and 9 females; mean age 24.3 years.
Study design:	Between-subjects.
Presence measures:	4 presence questions (naturalness of interaction, extent of presence, extent of involvement, extent things did and happened naturally without much mental effort), part of Swedish Viewer-User Presence (SVUP) questionnaire.
Task-related measures:	Enjoyment. <i>Also awareness of external/internal factors, sound quality, enjoyment, simulator sickness.</i>
Findings:	<ol style="list-style-type: none"> (1) Interaction had a significant effect on presence questions with actors reporting higher presence than observers. (2) <i>Interaction had a significant effect on enjoyment questions with actors reporting higher presence than observers.</i> (3) <i>Interaction had a significant effect on external awareness, with observers reporting higher awareness than actors; and a significant effect on internal awareness with actors reporting more awareness than observers.</i> (4) <i>Interaction had no significant effect ratings of sound quality.</i> (5) <i>Interaction had a significant effect on dizziness and headaches with actors reporting more symptoms than observers; but no significant effect on nausea, eye strain, problems concentrating, or feeling unpleasant.</i>

[Lawson, 1998] Lawson, J.P. September 1998. *Level of Presence or Engagement in One Experience as a Function of Disengagement from a Concurrent Experience*. M.Sc. Thesis. Naval Postgraduate School, Monterey, CA. See also Darken (1999).

Factors:	Visual display (HMD, mini-Cave, flat screen), audio cues (present, absent), directions (attend to VE and videotape, attend to VE).
Computing platform:	SGI Onyx RE-2 workstation with 4 194 IP25 MHz MIPS R10000 processors, Infinite Reality graphic board, 128 MB 20-way leaved main memory, 4 MB texture memory, 1 MB secondary cache, Iris Audi Processor Version A2. Coryhpheus Software Designer’s Workbench, EasyTerrain and EasyScene, and Multigen software.
Visual display:	Virtual Research V8 HMD with resolution (640 × 3) × 480, FOV 60°, frame rate 18–24 fps; semi-circular mini-Cave using 3 Mitsubishi Model VS5071 40-inch rear projection screens with FOV 103°, frame rate 24 fps; 21-inch SGI Color monitor with resolution 1280 × 1024, FOV 33°, frame rate 30 fps. 20-inch monitor for viewing videotape. Participant seated with monitor for videotape display placed just off to the side in clear view.
Audio display:	Headphones, attached to HMD as appropriate.
Tracking:	Polhemus 3Space Fastrak for head tracking.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Variation of H.G. Wells’ <i>War of the Worlds</i> sited in SGI Performer Town.
Videotape:	Aardman Animations Ltd. short subject <i>Wallace and Gromit</i> videotape.
Training:	None.

Experimental task: While on an automated car tour, observe the invasion of the town and various events. Videotape started a few minutes prior to start of VE guided tour.

Participants: 70 participants; 52 males, 18 females; mean age 37 years.

Study design: Between-subjects.

Presence measures: Engagement scores (VE quiz – RE quiz score), VE quiz score, RE quiz score, 32-item Witmer-Singer PQ Version 2.0.

Person-related measures: Witmer-Singer ITQ.

Findings: (1) VE quiz scores had a significant positive correlation with PQ scores.
 (2) ITQ had no significant correlation with VE quiz scores.
 (3) Visual display had no significant effect on engagement score and VE quiz score, but a significant effect on RE quiz scores with higher engagement found for mini-Cave than HMD condition.
 (4) Audio cues had no significant effect on engagement scores, but a significant positive effect on each of VE and RE quiz scores.
 (5) Directions had a significant effect on engagement scores and RE quiz scores, with participants who were directed to attend to both the VE and real world achieving lower scores; but no significant effect on VE quiz scores.

[Lok, 2003] Lok, B., S. Naik, M. Witton, and F.P. Brooks, Jr. 2003. "Effects of Handling Real Objects and Avatar Fidelity on Cognitive Task Performance in Virtual Environments." In *Proc. IEEE Virtual Reality 2003 Conference*, 22–26 March, Los Angeles, CA. 125–132.

Factors: Haptic cues (VE with real objects, VE with virtual objects), self-representation (generic with rubber gloves, visually faithful).

Computing platform: SGI Reality Monster, using 1 rendering pipe at 20 fps for pure VE condition and 4 rendering pipes at 12–20 fps for hybrid condition. 4 NTSC resolution cameras for a 320 × 240 resolution reconstruction. Latency .03 sec, and 1 cm reconstruction error.

Visual display: Virtual Research V8 HMD with 640 × 480 resolution per eye for VE. Television for real world.

Tracking: UNC Hi-Ball tracker for head tracking, with Polhemus Fastrak trackers for Pinch gloves.

Object manipulation: Using Fakespace Pinch gloves in VE with virtual objects. Using yellow dishwashing gloves in hybrid VE.

Virtual world: Virtual room including a lamp, a plant and a painting, and a virtual table registered with a real Styrofoam table. Participant standing in front of table on which blocks were placed. Self-representation in purely VE condition was neutral gray, generic. Self-representation in hybrid VE with accurate shape and generic appearance or visually faithful appearance.

Training: Practice task in real world using 6 block patterns (viewing blocks on television only), and 4 block patterns in VE.

Experimental task: Block arrangement task based on the Wechsler Adult Intelligent Scale, involving reasoning, problem solving, and spatial visualization. Involved small 4-block patterns and large 9-block patterns in 10 patterns (6 real timed, 4 VE timed).

Participants: 40 participants, including 31 computer science undergraduates; 33 males, 7 females. Required to have taken or be enrolled in a higher-level mathematics course.

Study design: All participants performed the block arrange task first in the real world. Subsequently a between-subjects design for experimental conditions.

Presence measures: Expanded SUS Questionnaire.

Person-related measures: *Guilford-Zimmerman Aptitude Survey Part 5: Spatial orientation.*

Task-related measures: *Kennedy SSQ.*

Performance measures: *Time to correctly replicate given patterns.*

Other measures: Self-report of task performance, rated on a 7-point scale.

- Findings:
- (1) Haptic cues and self-representation each had no significant effect on presence.
 - (2) *Haptic cues had a significant effect on performance with improved performance for the hybrid VE compared to the VE with virtual objects.*
 - (3) *Self-representation had a significant effect on task performance, with improved performance for the visually faithful self-representation than for the VE with virtual objects, but no significant effect for the hybrid VE with generic self-representation.*
 - (4) *Experimental conditions had a significant effect on self-reports of performance with higher reported performance for the hybrid VE with visually faithful self-representation than the VE with virtual objects and generic self-representation.*
 - (5) *Experimental conditions had no significant effect on SSQ scores.*
 - (6) *Spatial ability had no relationship with task performance.*
-

[Mania, 2001] Mania, K. and A. Chalmers. 2001. "The Effects of Levels of Immersion on Memory and Presence in Virtual Environments: A Reality Centered Approach." *CyberPsychology & Behavior*, 4(2), 247–263.

- Factors: Environment type (HMD, 3D desktop, real, audio-only).
- Visual display: Custom see-through, non-stereoscopic HMD with FOV approx. 30°H, resolution 1024 × 764. 21-inch monitor with FOV approx. 35°H, resolution 1152 × 864. Average update rate 45 fps. Rendered flat-shaded.
- Tracking: None.
- Navigation: For visual conditions, using standard mouse to explore room from a steady viewpoint, approx. placed in center of room, with ability to move in a full circle.
- Object manipulation: None.
- Virtual world: Model of a university seminar room. Including slide show to present 12 'overhead' slides synchronized with audio taken from digital video recording from real condition.
- Experimental task: Attend a 15-minute seminar on a non-science topic. (Real condition included presentation of 12 slides on an overhead projector.)
- Participants: 4 groups of 18 participants from a university campus and Hewlett Packard Labs, Bristol, UK; 80% male. All used computers frequently in daily activities. No prior knowledge of seminar subject matter.
- Study design: Between-subjects.
- Presence measures: 6-item SUS presence questionnaire (slightly modified).
- Person-related measures: Game playing experience.
- Task-related measures: Kennedy SSQ, confidence ratings and memory awareness states (guess, familiar, remember, know) included with memory recall and spatial awareness questionnaire.
- Performance measures: 22-item memory recall. *Also spatial awareness questionnaire.*
- Findings:
- (1) Environment type had a significant effect on presence overall, and for all questions except 1 (images seen or heard compared with place visited), with higher presence reported for real condition than other 3 conditions. No significant difference in presence between the desktop, HMD, or audio-only conditions.
 - (2) Game playing experience had no significant correlation with presence.
 - (3) Total SSQ score had no significant correlation with presence in the HMD condition.
 - (4) Memory recall had no significant correlation with presence.
 - (5) *Environment type had a significant effect on memory recall, with increased recall in the real condition compared to the HMD and audio-only conditions; but no significant difference between real and desktop environments, or between audio-only, HMD, and desktop conditions.*
 - (6) *For memory recall, environment type had a significant effect on confidence ratings, with increased confidence reported for the real condition than desktop*

- condition, and for the desktop condition than HMD condition, and audio-only conditions than HMD condition.
- (7) For memory recall, environment type had a significant effect on memory awareness states with more “guesses” made for HMD than either real or audio-only conditions only. Also a significantly higher probability that “guess” responses were correct for real, HMD, and audio-only conditions than desktop condition.
 - (8) Visual stimulation had a significant positive effect on memory recall performance with better performance for questions with answers written on slides and communicated aurally for the desktop than audio-only condition.
 - (9) Environment type had no significant effect on spatial awareness.
 - (10) For spatial awareness, environment type had no significant effect on confidence ratings.
 - (11) For spatial awareness, environment type had a significant effect on memory awareness states with the probability of “remember” responses being correct higher for HMD compared to real conditions, but not desktop; and the probability of “familiar” responses being correct higher for the real compared to HMD conditions.

[Mania, 2000] Mania, K. and A. Chalmers. 2000. “A User-Centered Methodology for Investigation Presence and Task Performance.” Available at http://www.cs.bric.ac.uk/~mania/presence_workshop2000/submit_presence.html.

Factors:	Environment type (real, virtual with audio, audio only).
Computing platform:	PC with hardware accelerator. In-house VRML and Java software.
Visual display:	21-inch monitor. Frame rate 40 fps
Navigation:	For visual conditions, using standard mouse to explore room from a steady viewpoint, approx. placed in center of room, with ability to move in a full circle, as well as emulating head movement.
Object manipulation:	None.
Virtual world:	Model of a university seminar room using static billboard with texture to display lecturer, and slide show to present 12 ‘overhead’ slides. Slides synchronized with audio taken from digital video recording of real condition.
Experimental task:	Attend a seminar in form of a 15-minute lecture (included 12 slides shown on an overhead projector in real condition).
Participants:	3 groups of 18 participants.
Study design:	Between-subjects.
Presence measures:	SUS questionnaire.
Performance measures:	16-item knowledge acquisition and 6-item environment perception questionnaire (latter part not used in audio only condition).
Findings:	<ul style="list-style-type: none"> (1) Environment type had a significant effect on presence, with more presence reported for the real condition than for either the virtual or audio only condition, but no significant difference between the virtual and audio only conditions. (2) Task performance had no significant correlation with presence. (3) <i>Environment type had a significant effect on task performance, with improved performance found for real and audio-only conditions, but no significant difference for virtual with audio condition.</i> (4) <i>Visual stimulation had a significant positive effect on task performance with better performance for questions with answers written on slides and mentioned by lecturer for the real and virtual conditions compared to audio-only.</i>

[Meehan, 2003] Meehan, M.S. Razzaque, M.C. Whitton, and F.P. Brooks, Jr. 2003. “Effect of Latency on Presence in Stressful Virtual Environments.” In *Proc. IEEE Virtual Reality 2003 Conference*, 22–26 March, Los Angeles, CA. 141–148.

Factors:	End-to-end latency (~50ms, ~90ms).
Computing Platform:	Pentium 4 1.8 GHz with a dual nVidia GeForce Ti 4600 graphics card and Creative Labs Audigy sound card. Modified WildMagic software game engine. Additional PCs for data recording and viewing.
Visual Display:	Virtual Research V8 HMD with 640 × 480 resolution for each eye, 60° diagonal FOV, refresh rate 60Hz. IPD adjusted for each participant.
Audio display:	Sennahesier HD 250 II sealed circumaural headphones replacing standard HMD headphones to provide spatialized background music coming from a virtual radio and instructions from a virtual wall-mounted speaker.
Haptic display:	Passive haptics using a real 1.5-inch wooden ledge, walls, and counters. Fan (and moving curtains) to simulate wind.
Tacking:	3 rd Tech HiBall 3000 tracker for head and hand position.
Physiological devices:	Thought Technologies Ltd. ProComp+ Tethered Telemetry system, sampling skin conductance at 32Hz and EKG at 256Hz. Essilor Digital C.R.P. pupillometer for measuring participant IPD.
Virtual world:	Slater's virtual pit environment consisting of a training room and door leading to a 2-story tall pit room with 2ft ledge around a 20ft chasm.
Training:	5 minutes used to familiarize participants with hardware devices and cable management. In practice VE room, responded to instructions to navigate around the room, and pick up and drop bean bags.
Experimental task:	Following recorded instructions, enter Pit Room, test a real 1.5-inch wooden ledge with feet, and drop two beanbags on target areas in the chasm.
Participants:	164 SIGGRAPH 2002 conference participants; 132 male, 32 female; average age 35; in good physical condition.
Study design:	Between-subjects.
Presence measures:	Shortened version of UCL Questionnaire with 1 item to rate amount of fear experienced and 5 presence items based on SUS Questionnaire with values of '5,' '6,' and '7' used for high presence rating, Δ heart rate (data available for only 61 participants), Δ skin conductance (data available for only 67 participants).
Task-related measures:	Kennedy SSQ. <i>Also self-reported fear.</i>
Findings:	<ol style="list-style-type: none"> (1) Latency had no significant effect on presence and fear measured using the UCL questionnaire. (2) Latency had a borderline significant effect ($p = 0.05$) on Δheart rate with greater presence reported for the lower latency. (When the SSQ Nausea subscale was taken into account, this was a significant effect ($p < 0.05$) for Δheart rate.) (3) Latency had no significant effect on Δskin conductance. (4) SSQ Nausea subscale had a significant positive correlation with both Δheart rate and Δskin conductance. (5) <i>Reported fear had a significant positive correlation with SSQ total score and Nausea, Ocular Discomfort, and Disorientation subscales.</i>

[Meehan, 2001a (1)] Meehan, M. March 2001. *Physiological Reactions as an Objective Measure of Presence*. Ph.D. Dissertation. University of North Carolina at Chapel Hill.

Factors:	Multiple exposures (2 to 12).
Computing platform:	SGI Reality Monster, using 1 Infinite Reality 2 pipe. In-house software.
Visual display:	Virtual Research V8 HMD, with 640 × 480 tri-color pixel resolution per eye. Update rate generally 30 fps.
Haptic display:	Real 1.5-inch high plywood ledge registered with virtual ledge over chasm.
Tracking:	Large-area optical tracking system using UNC Tech Hi-Ball, allowing movement in 4 × 10m area. Movement lag ~100msec.
Navigation:	Actual walking.
Object manipulation:	Hand control with push buttons.

Virtual world:	Pit room entered from training room. In the pit room, a 20ft chasm surrounded by a 2ft walkway, with a ledge extending over the chasm. Area 18 × 32ft. Virtual environment ranged from 10,000–20,000 polygons, with 41–50 Mbytes texture mapping. Self-representation as virtual body.
Training:	Training room where users learn to navigate and pick up and move a virtual book. Approximately 2 minutes.
Experimental task:	Carry a virtual book into the pit room and place on a chair on the far side of the pit from the entrance. Typically took 40 seconds
Participants:	10 participants; 3 male, 7 female, mean age 24.4 years. Three or fewer prior experiences of immersive VEs, could use stereopsis for depth perception, no history of epilepsy or seizure, not overly prone to motion sickness, in usual good physical fitness, comfortable with equipment.
Study design:	Within-subjects.
Presence measures:	Δskin conductance level, Δskin temperature, UCL questionnaire. Observed behavioral measures: count of behaviors believed to be associated with moving about near a real 20ft drop, such as slower motion, leaning against wall, testing edge with foot, and vocal exclamation.
<i>Person-related measures: Age, race, gender, association with virtual body, computer usage, height anxiety and avoidance.</i>	
Task-related measures:	Kennedy SSQ.
Findings:	<ol style="list-style-type: none"> (1) Repeated exposures had a significant negative effect on Δskin temperature and reported behavioral presence after the first exposure only, and on observed behavioral presence on subsequent days. It had a significant positive effect on Δskin conductance. No significant effect on other presence measures. (2) Δskin conductance, Δskin temperature, and observed behavioral presence had no significant correlation with either reported presence or reported behavioral presence. (3) <i>Person-related measures and SSQ scores had no significant correlation with multiple exposures.</i>

[Meehan, 2001a (2)] Meehan, M. March 2001. *Physiological Reactions as an Objective Measure of Presence*. Ph.D. Dissertation. University of North Carolina at Chapel Hill. See also Insko (2001) and Meehan (2001b).

Factors:	Haptic cues (mixed reality wooden ledge, virtual ledge only).
Computing platform	Virtual world: As above.
Training:	As above, but included viewing pit room from doorway.
Experimental task:	Carry a virtual book into the pit room and to the end of a wooden diving board, count to 10 and look around. Then carry book to a chair on the far side of the pit from the entrance. Pit surrounded by a narrow ledge. Typically took 90 seconds.
Participants:	52 participants; 36 males, 16 females; mean age 21.4 years. Meeting same conditions as [Meehan 2001a (1)] above.
Study design:	Within-subjects.
Presence measures	Task-related measures: As above, with Δheart rate added to Presence measures.
Findings:	<ol style="list-style-type: none"> (1) Haptic cues had a significant positive effect on Δheart rate, Δskin conductance, observed behavior, and reported behavioral presence, but no significant effect on reported presence or Δskin temperature. (2) Δheart rate, Δskin conductance, and Δskin temperature had no significant correlation with either reported presence or reported behavioral presence. Observed behavioral presence had no significant correlation with reported presence, but a significant positive correlation with reported behavioral presence. (3) Repeated exposures had a significant negative effect on reported presence and reported behavioral presence after the first exposure only. No significant effect for other presence measures.

(4) *Person-related measures (except for game playing) and SSQ scores had no significant correlation with haptic cues.*

[Meehan, 2001a (3)] Meehan, M. March 2001. *Physiological Reactions as an Objective Measure of Presence*. PhD Dissertation University of North Carolina at Chapel Hill. Also Meehan (2001b).

Factors: Frame rate (10, 15, 20, 30 fps).
 Computing platform... Training: As above.
 Experimental task: Carry a virtual block into the pit room and drop it over a spot marked on floor of pit, then grab additional blocks floating in the air drop those at other locations marked on the pit floor. Typically took 90 seconds.
 Participants: 33 participants; 25 males, 8 females; mean age 22.3 years. Meeting same conditions as [Meehan 2001a (1)] above.
 Study design: Within-subjects.
 Presence measures: Task-related measures: As above.
 Findings: (1) Frame rate had a significant effect on Δ heart rate, Δ skin conductance, Δ skin temperature, reported presence, reported behavioral presence, and observed behavioral presence, except for 10 fps.
 (2) Δ heart rate, Δ skin conductance, Δ skin temperature, and observed behavioral presence had no significant correlation with either reported presence or reported behavioral presence.
 (3) Observed behavioral presence had no significant correlation with reported presence, but a significant positive correlation with reported behavioral presence.
 (3) Repeated exposures had a significant negative effect on Δ skin conductance, Δ skin temperature, and observed behavioral presence after first exposure only; and on Δ heart rate and reported behavioral presence over exposures on the same day. No significant effect on reported presence.
 (4) *Person-related measures and SSQ scores had no significant correlation with frame rate.*

[Nichols, 2000 (1)] Nichols, S., C. Haldane, and J.R. Wilson. 2000. "Measurement of Presence and Its Consequences in Virtual Environments." *Inter. Journal of Human-Computer Studies*, 52, 471–491.

Factor: Visual display (HMD, desktop), audio cues (present, absent).
 Computing platform: Pentium 133 PC, with Superscape VRT software. Frame rate ~10 fps with tracker delay of 4ms.
 Visual display: I-glasses HMD.
 Audio display: Headphones embedded in HMD.
 Navigation: Using head movements to alter viewpoint.
 Object manipulation: Using 3D mouse.
 Virtual world: "Duck shoot" fairground stall. Percentage accuracy and number of ducks shot displayed on the screen and participants given an incentive to perform well by being told a financial bonus would go to the top 5 high scorers. Startle event occurred between 5 and 6 minutes and consisted of a duck that had been hit zooming out into the foreground and "exploding." Non-directional sound cues consisted of continual duck quacking noises with a special quack when shot.
 Experimental task: Play fairground game. 10 minute time limit.
 Participants: 24 undergraduate students; 12 males, 12 females; age range 18 to 25 years. No prior experience of VEs.
 Study design: Within-subjects for type of visual display, between-subjects for audio cues.
 Presence measures: Reaction to a randomly timed "startle event," recall of different types of background music played in the lab that were out of context with the virtual world, and Nichol's questionnaire.

Task-related measures: Short Symptom Checklist (SSC) for simulator sickness.

- Findings:
- (1) Visual display had a significant effect for reflex response presence measure with greater response found for the HMD, but no significant difference for background awareness presence measure. For the questionnaire, type of visual display had a significant effect on “being” and “visit” presence items only.
 - (2) Audio cues had a significant positive effect on reflex response presence measure for HMD users, but no significant effect on background awareness presence measure. For the questionnaire, audio cues had no significant effect on presence items.
 - (3) For HMD condition, total SSC scores had no significant correlation with any presence measure.
 - (4) All presence items had a significant positive correlation with the reflex response measure. The background awareness measure had a significant negative correlation with visit item only.
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[Nichols, 2000 (2)] Nichols, S., C. Haldane, and J.R. Wilson. 2000. “Measurement of Presence and Its Consequences in Virtual Environments.” *Inter. Journal of Human-Computer Studies*, 52, 471–491.

- Computing platform: Division Provision 100 VPX. Frame rate range 2–15 fps, with 20ms lag.
- Visual display: Division HMD.
- Navigation: Using head movements to alter viewpoint.
- Object manipulation: Using 3D mouse.
- Virtual world: Virtual house.
- Experimental task: Explore rooms in house and perform specified tasks in each room. (Tasks designed to ensure a range of physical movements, and both gross and small manipulation using hand-held 3D mouse.) Tasks included a 3D jigsaw puzzle, estimating reach distance and picking up pencils. 20 minute time limit.
- Participants: 20 participants; 10 males, 10 females; age range 18 to 41, mean age 24.5 years.
- Presence measures: Witmer-Singer PQ.
- Task-related measures: Kennedy’s SSQ, Adjectival Response Scale (ARS) measure of enjoyment. *Also* SSC.
- Findings:
- (1) PQ Interface subscale had a significant negative correlation with post-participation levels on SSQ total and all subscales.
 - (2) PQ Interface subscale had a significant positive correlation with reports of a positive experience. PQ Total and Involved/Control subscale each had a significant positive correlation with overall enjoyment.
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[Preston, 1998] Preston, L. November 1998. *The Use of Virtual Reality in the Reduction of Stress*. Honours thesis. Computer Science Department, Rhodes University. South Africa.

- Factor: Level of interaction (interaction with VE, watching video through HMD).
- Computing platform: SGI O2. RhoVeR software system with CoRgi Toolkit.
- Visual display: General Reality CyberEye HMD. Frame rate 6–8 fps. Participants seated in a swivel chair positioned in a darkened room.
- Audio display: HMD headphones.
- Tracking: Polhemus InsideTrak for head and hand tracking.
- Navigation: Using a handheld stick with 4 switches to control movement.
- Object manipulation: Using the handheld stick, clicking switches to move corresponding fingers on virtual hand.
- Virtual world: Derived from SGI’s underwater demo environment where participant can interact with a range of marine mammals, modified so that dolphins show curiosity about the diver and spend a portion of their time in the diver’s vicinity. Participants swim around, touch a dolphin or swaying sea plant, and ride a dolphin. Images

constructed from smoothed and shaded polyhedral objects with texture mapping. Musical background. Self-representation as virtual hand.

Experimental task: Swim with dolphins. 5 minute time limit.

Participants: 35 university students; 23 male, 12 female; 4 participants between 10 and 20 years, 31 participants between 21 and 30 years.

Study design: Within-subjects.

Presence measures: Δ heart rate. *Also 1-item presence questionnaire.*

Findings: (1) Level of interaction had no significant effect on Δ heart rate.

[Prothero, 1995a (1)] Prothero, J.D., H.G. Hoffman, D.E. Parker, T.A. Furness III, and M.J. Wells. 1995. "Foreground/Background Manipulations Affect Presence." In *Proc. Human Factors and Ergonomics Society 39th Annual Meeting*, San Diego, CA. 1410–1414.

Factors: Visual scene (as foreground, as background).

Computing platform: Division Ltd. ProVision 100 system.

Visual display: Division Ltd. dVisor HMD with 40°V × 105°H, 40° overlap. Eye mask provided by Lucas Products Corp. Super Sunnies tanning goggles with central ultraviolet protectors removed, providing FOV 40° direct, 60° peripheral, or screen mask provided by paper mask mounted on HMD screens with 2.54 cm diameter holes providing FOV 60°.

Object manipulation: Virtual net slaved to real hand position.

Virtual world: Division's Sharkworld: a texture mapped underwater scene with a sunken ship and various moving sea creatures.

Experimental task: Catch sharks using a virtual net. 2.5-minute time limit.

Participants: 26 adults; 19 male, 7 female. 3 participants reported more than 10 minutes prior VE experience.

Study design: Within-subjects.

Presence measures: Prothero's questionnaire.

Findings: (1) Visual scene manipulation had a significant effect on overall presence score and each item separately, with more presence reported when virtual scene was perceived as background.
(2) Order had a significant effect such that the difference between conditions was significant only when the eye mask was used first.

[Prothero, 1995a (2)] Prothero, J.D., H.G. Hoffman, D.E. Parker, T.A. Furness III, and M.J. Wells. 1995. "Foreground/Background Manipulations Affect Presence." In *Proc. Human Factors and Ergonomics Society 39th Annual Meeting*, San Diego, CA. 1410–1414.

Factors...Presence measures: As in [Prothero, 1995a (1)] above, except for Participants: 13 adults; 9 male, 4 female. 1 participant reported more than 10 minutes prior experience. Conducted as double-blind experiment.

Findings: (1) Visual perimeter had a significant effect overall presence score, with more presence reported when virtual scene was perceived as background.

[Prothero, 1995b] Prothero, J.D. and H.G. Hoffman. 1995. *Widening the Field-of-View Increases the Sense of Presence in Immersive Virtual Environments*. Available at <http://www.hitl.washington.edu/publications/r-95-5/>.

Factors: Field of view (unrestricted, direct 40°, peripheral 60°).

Computing platform: Division Ltd. ProVision 100 system.

Visual display: Division Ltd. dVisor HMD with 40°V × 105°H, 40° overlap. Eye mask provided by Lucas Products Corp. Super Sunnies tanning goggles with central ultraviolet protectors removed.

Tracking...Presence measures: As in [Prothero, 1995a (1)] above, except Participants: 38 high school students; 20 males, 18 females; age range 16–18 years. No participants reported more than 10 minutes prior experience.

Person-related measures: Gender.

Findings: (1) FOV had a significant effect on overall presence score, with increased presence reported for unrestricted FOV. When analyzed separately, a significant difference was found for only 2 items (felt like standing in lab as opposed to the virtual world, reality of the virtual world).
 (2) Gender had a significant effect on presence.
 (3) Order had a significant effect on presence such that the difference between conditions was significant only when the eye mask was used first.

[Regenbrecht, 1998] Regenbrecht, H.T., T.W. Schubert, and F. Friedman. 1998a. "Measuring the Sense of Presence and Its Relations to Fear of Heights in Virtual Environments." *Inter. Journal of Human-Computer Interaction*, 10(3), 233–249. See also Regenbrecht (1997).

Computing platform: Super Graphics Workstation.

Visual display: Monoscopic, color Virtual Reality VR4 HMD. Subject standing on wooden platform that provided an unrestricted interaction space ~4m in diameter.

Tracking: Polhemus tracking devices.

Object manipulation: None.

Virtual world: Virtual world with a virtual cliff approx. 8m high achieved by lowering parts of the ground. Depth cues provided using linear perspective enhancing lines at edges, special face coloring, and some architectural elements as a reference frame. No texture mapping, no advanced lighting.

Training: 2 minutes spent in virtual world before part of the ground was lowered to form a chasm and cliffs.

Experimental task: Search for some texts in the virtual world and obey instructions given by these texts; these instructions required a subject to move around the virtual world. All tasks were completed if an exit sign was found. 20 minutes time limit.

Participants: 37 students and university employees; 23 males, 14 women; age range 20 to 46, mean age 27 years. Participants had little or no prior experience with VEs. Non-phobic.

Presence measures: Regenbrecht's questionnaire.

Person-related measures: Fear of heights and avoidance behavior questionnaire.

Task-related measures: 20-item State-Trait Anxiety Index.

Findings: (1) Presence and fear of heights had significant positive effects on experienced fear.
 (2) *Avoidance behavior had a significant negative effect on experienced fear.*

[Riley, 2001] Riley, J.M. 2001. *The Utility of Measures of Attention and Situation Awareness for Quantifying Telepresence*. Ph.D. Dissertation. Mississippi State University. MS.

Factors: Task complexity (low mine density, moderate mine density, high mine density).

Computing platform: Intergraph TDZ2000GXI workstation with high-performance graphics subsystems and a Dell PC.

Visual display: Two 21-inch graphics monitors with 1280 × 1024 resolution, viewed using CrystalEyes stereographic goggles.

Navigation: Standard mouse used to navigate a simulated robotic vehicle.

Object manipulation: Keyboard used to give commands to robotic vehicle.

Virtual world:	Audio cues used to present a ringing bell sound whenever part of the robot was directly over a landmine, and an auditory signal marking collisions with objects.
Training:	First training period provided instruction on how to operate the simulated robotic vehicle for teleoperation tasks using the mouse controller, and how to manipulate the robotic arm using keyboard and voice commands. Included instruction, demonstration, and hands-on practice. Second training period provided instruction, demonstration, and hands-on practice using the keyboard for completing secondary monitoring tasks, also practice of both tasks performed simultaneously. Third training session provided explanation of SAGAT queries and survey administration during trials, with practice including multi-task performance involving SAGAT freezes and queries. Total time 2 hours.
Experimental task:	The primary task was to operate a robotic vehicle (via voice commands) to locate, uncover, identify, and neutralize 4 landmines. Secondary tasks were to monitor displays for visual signals indicating a critical event associated with the rover and controls in the teleoperation task (one given in VE and other in RE). 30 to 50 minutes. Two trials.
Participants:	24 university students; 22 male, 2 female; age range 19 to 26, mean age 20.25 years. Participants with 20/20 normal or corrected-to-normal visual acuity, right handed, experience using PCs, and video game experience.
Study design:	Between-subjects.
Presence measures:	19-item subset of Witmer-Singer PQ.
Person-related measures:	18-item subset of Witmer-Singer ITQ. <i>Also anthropometric survey.</i>
Task-related measures:	Modified Cooper-Harper perceived workload scale, SAGAT queries for average situation awareness, hit-to-signal ratios for attention to each monitoring task, and comparison of ratios across monitoring environments.
Performance measures:	Average time-to-mine neutralization.
Findings:	<ol style="list-style-type: none"> (1) Task complexity had a significant negative effect on presence. (2) Presence had no significant relationship with average situation awareness or the ratio of attention scores across VE to RE environment. (3) Presence had a significant negative correlation with average time-to-mine neutralization, perceived workload, and hit-to-signal ratio in VE. (4) Presence had a significant positive correlation with ITQ. (5) <i>Task complexity had a significant negative effect on performance.</i> (6) <i>Task performance had a significant negative correlation with perceived workload, average situation awareness, and hit-to-signal ratio in VE.</i> (7) <i>Average situation awareness had a significant positive correlation with perceived workload, the ratio of attention across the VE and RE, and hit-to-signal ratio in VE.</i> (8) <i>Task complexity had no significant effect on situation awareness, attention, or workload.</i>

[Riley, 1999] Riley, J.M. and D.B. Kaber. 1999. "The Effects of Visual Display Type and Navigational Aid on Performance, Presence, and Workload in Virtual Reality Training of Telerover Navigation." In *Proc. Human Factors and Ergonomics Society 43rd Annual Meeting*. 1251–1255.

Factors:	Display type (HMD, projection screen, monitor), navigational aid (written directions, plan-view layout).
Visual display:	HMD with 640 × 480 resolution, large projection screen with 600 × 800 resolution, computer monitor with 1280 × 1024 resolution.
Navigation:	Using standard mouse.
Object manipulation:	None.
Experimental task:	Navigate a simulated telerobotic vehicle through an office environment consisting of nine rooms, and three independent paths. Two trials.
Participants:	24 participants; age range 20 to 42 years.

Study design: Mixed, with display type as between-subjects factor, and navigational aid as within-subjects factor.

Presence measures: Witmer-Singer PQ.

Person-related measures: Witmer-Singer ITQ, Manikin Test, Carter and Wolstad spatial ability test.

Task-related measures: NASA-Task Load Index (TLX).

Performance measures: Task completion time, route selection.

Findings:

- (1) Display type had a significant effect on presence, with higher ratings for presence given for monitor.
- (2) Presence significantly increased over the two trials.
- (3) ITQ had a significant positive correlation with presence.
- (4) Task performance had a significant negative correlation with presence for map users.
- (5) Workload had a significant negative correlation with presence.
- (6) Spatial ability had a significant correlation with presence, but not task performance or workload.
- (7) *Display type had no significant effect on performance or workload.*
- (8) *Navigation aid had a significant effect on both navigation time and selection of most efficient route, with increased performance found for map usage.*
- (9) *Navigation aid had a significant effect on perceived workload, with a lower level of workload reported for map usage.*

[Romano, 1998] Romano, D.M., P. Brna, and J.A. Self. 1998. "Collaborative Decision Making and Presence in Shared Dynamic Virtual Environments." In *Proc. 1st International Workshop on Presence in Shared Virtual Environments at BT Labs*, Ipswich, UK. See also Romano (2001).

Factors: Collaboration (playing game as a team of two, individually).

Computing platform: 2 multimedia PCs.

Visual display: Two 15-inch desktop monitors.

Navigation: Combination of standard 2DOF mouse and arrow keys.

Object manipulation: Combination of standard 2DOF mouse and arrow keys

Virtual world: Multi-participant virtual game where virtual world has constraints similar to reality, e.g., participant has to breathe while swimming and dies if shot by hostile creatures. Limited number of lives. Self-representation as gun.

Training: Preliminary training on basic game features for those with no prior experience.

Experimental task: Find way out of maze while surviving the attack of other humans and animals.

Participants: 6 pairs of participants; 5 males and 7 females; 10-year age range from mid-20s to mid-30s. Participants knew their partners prior to the study.

Study design: Within-subjects.

Presence measures: 3-item Romano's presence, 6-item Romano's co-presence questionnaires.

Person-related measures: Game playing experience.

Task-related measures: Self-rating of collaboration and performance.

Findings:

- (1) Collaboration had a positive effect on co-presence.
- (2) Self-rating of performance had a positive correlation with presence.
- (3) Game experience had a positive relationship with presence.
- (4) 92% of participants felt they were in the place they were looking at on the screen always (58%) or sometimes (33%).
- (5) 33% of participants felt their partner was always in the virtual world, 67% felt he was sometimes in the virtual world. 58% felt they were both in the virtual world and that collaboration was possible even if they did not see their partner on the screen. 33% felt their collaboration was enhanced when they could see their partner and sometimes they both felt themselves to be in the virtual world.

[Sallnäs, 1999] Sallnäs, E.-L. 1999. "Presence in Multimodal Interfaces." In *Proc. 2nd Inter. Workshop on Presence*, University of Essex, UK. Available at <http://www.nada.kth.se/~evalotta/Presence/IWVP.html>. See also Sallnäs (2000).

Factors: Haptic force feedback (present, absent).
 Computing platform: Intergraph workstation. Software developed using GHOST Software Development Kit.
 Visual display: Two 21-inch desktop monitors.
 Audio display: GN Netcom audio headsets using a telephone connection.
 Haptic display: Two SensAble Technologies Inc. PHANToMs, an "A" and "T" model.
 Navigation: Using haptic display.
 Object manipulation: Using haptic display, one participant can push cubes along the floor or lift a cube by pressing it against a wall and pushing it up, or work together in lifting a cube. When no haptic feedback is provided, PHANToM operates as a 3D mouse.
 Virtual world: Room containing 8 cubes with simulated form, mass, damping and surface friction. A slight vibration distinguished between touching a cube and touching or holding on to partner. Force feedback also provided for walls and partner. Self-representation as colored sphere 12 mm in diameter.
 Training: Approx. 2 minutes learning the interface.
 Experimental task: Five collaborative tasks. Four tasks require building patterns with cubes, other requires navigating through a constructed pattern.
 Participants: 14 pairs of university students; 14 males, 14 females; age range 20 to 31, mean age 23 years. No prior experience with collaborative desktop virtual interfaces. Participants did not know each other or meet prior to the experiment.
 Study design: Between groups.
 Presence measures: 32-item Witmer-Singer PQ Version 2.0, Sallnäs's social presence questionnaire.
 Task-related measures: 14-item perceived performance questionnaire.
Performance measures: Time to complete task.
 Findings: (1) Haptic force feedback had a significant positive effect on presence and perceived task performance, but no significant effect on social presence.
 (2) *Haptic force feedback significantly reduced task completion time.*

[Sas, 2001] Sas, C. and G. O'Hare. 2001. *The Presence Equation: An Investigation into Cognitive Factors Underlying Presence*. University College Dublin, Dept. of Computer Science. UK.

Factors: Cognitive style (absorption, creative imagination, empathy, cognitive type), gender.
 Virtual world: ECHOES training environment for maintenance of complex industrial artifacts. Provides a virtual 4-story building, with numerous rooms on each floor, including a conference room, lobby room, training room, and elevator. Specific user activities are associated with each room.
 Training: Exploratory task to gain familiarity with the environment and navigation control. 25 minute time limit.
 Experimental task: Search tasks including finding a hidden painting, and finding the library and specific information within the library given spatial landmarks.
 Participants: 15 undergraduate and postgraduate students; 9 males, 6 females; age range 20 to 38 years.
 Study design: Within-subjects.
 Presence measures: Sas's questionnaire, SUS questionnaire.
 Person-related measures: Psychological battery test comprising the Tellegen Absorption Scale, Creative Imagination Scale, Davis' Interpersonal Reactivity Index, and Myers Briggs Type Indicator.
 Findings: (1) Creative imagination score and interpersonal reactivity index each had a significant positive correlation with presence. Absorption and cognitive type had no significant correlation with presence.

- (2) Gender had no significant effect on presence, absorption, or creative imagination, but a significant effect on empathy with increased empathy reported for females.
- (3) Presence score had a significant positive correlation with SUS questionnaire score.

[Schroeder, 2001] Schroeder, R., A. Steed, A.-S. Axelsson, I. Heldal, Å. Abelin, J. Wideström, A. Nilsson, and M. Slater. 2001. "Collaborating in Networked Immersive Spaces: As Good As Being Together?" *Computers & Graphics*, 25, 781–788.

Factors:	Environment type (1 participant in each of 2 projection displays, 1 participant in projection display and 1 participant using desktop, real world).
Computing platform:	SGI Onyx2 Infinite Reality with 14 250 MHz R10000 MIPS processors, 2 GB RAM, 3 Infinite Reality graphics pipes. SGI Onyx2 with 8 300 MHz R12000 MIPS processors, 8 GB RAM, 4 Infinite Reality graphics pipes. SGI O2 with 1 MIPS R1000 processor, 256 MB RAM. DIVE toolkit, DIVEBONE connection, and dVise 6.0 software with SGI Performer renderer. Network lag ~180ms between Onyx 2 systems, less between the first and third systems.
Visual display:	3 × 3 × 3m TAN VR-CUBE with projection on 5 walls (no ceiling), stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses; rendering performance at least 30Hz. Trimension ReaCTor with projections on 3 × 2.2m walls and 3 × 3m floor, stereoscopic viewing CrystalEyes shutter glasses; rendering performance 45Hz. 19-inch monitor; rendering performance at least 20Hz.
Audio display:	Robust Audio Toolkit for communication between participants, except on one occasion when 2 mobile phones were used.
Tracking:	Polhemus tracking of both shutter glasses and hand for VR-CUBE, Intersense IS900 system tracking for shutter glasses and interaction device for ReaCTor.
Navigation:	Using 3D wand with VR-CUBE system, interaction device with 4 buttons and analogue joystick with ReaCTor system (locomotion enabled), by moving middle button on a standard 3-button mouse with desktop system.
Object manipulation:	Select objects by putting virtual hand into a virtual cube and press/release wand/joystick button to move object, or by using standard mouse buttons.
Virtual world:	Participant represented to partner as a simple human-like male avatar with jointed arm, self-representation as virtual hand.
Experimental task:	Two participants cooperate to solve a puzzle by arranging 8 30 cm ³ colored blocks into a cube such that each side of the completed cube displays a single color. 20 minute time limit.
Participants:	132 participants (22 pairs in each of 3 display groups).
Presence measures:	Schroeder's questionnaire.
Task-related measures:	3 items on collaboration, 3 items on contribution to task questionnaire.
Performance measures:	Time to complete task.
Findings:	<ol style="list-style-type: none"> (1) Visual display had a significant effect on each item of object presence, with higher presence reported by immersed participants compared to desktop participants. Type of immersive display had no significant effect. (2) Visual display had a significant effect on place presence, with higher presence reported by immersed participants compared to desktop participants. Immersed participants whose partners used an immersive display reported significantly more place presence than those whose partners used the desktop. (3) Visual display had a significant effect on co-presence, with immersed participants using the 5-wall Cave reporting higher presence than desktop users. There was no significant difference between 4-wall Cave and desktop participants. Also, participants who were both immersed reported significant higher presence than the immersed participant (5-wall Cave) with desktop partner. (4) Environment type (real and 2 participants using projection displays) had no significant effect on time to complete task. (5) Visual display had no significant effect on rating of collaboration.

- (6) *Visual display had a significant effect on rating of contribution, such that immersive participants were rated as more active than desktop participants, but no significant difference in amount of verbal communication.*

[Schubert, 2000 (1)] Schubert, T., H. Regenbrecht, and F. Friedmann. 2000. *Real and Illusory Interaction Enhance Presence in Virtual Environments*. Submitted to *Presence 2000, 3rd International Workshop on Presence*. See also Regenbrecht (2000, 2002).

Factors:	Type of movement (self-movement, preset), agents (present, absent).
Computing platform:	SGI workstation.
Visual display:	Virtual Research VR4 HMD. Update rate ~15Hz. In preset movement condition, a pre-recorded, film-like presentation showing the VE from the viewpoint of a person slowly wandering and looking around was presented on the HMD. Participant standing.
Tracking:	Polhemus Fastrak for head tracking in self-movement condition.
Navigation:	When viewpoint was under participant control, participant could change viewpoint by turning his head and/or walking around in a circle 5m in diameter. In other condition, participant had no control of navigation.
Object manipulation:	None.
Virtual world:	Hallway representing an administration building. Participant stands at an intersection, looking into 4 corridors with numerous doors. Across the wall, a number of plates are visible. Circle boundary marked with red line. In the agent's present condition, doors opened and closed from time to time and 2 comic-strip-like shoes came out of the doors, walked across the hall and entered other rooms.
Training:	Brief verbal description of the VE technology, especially the HMD, and the virtual world participants would experience.
Experimental task:	Count number of plates on the wall. 5 minute time limit.
Participants:	56 students and university staff member; 34 males, 22 females; age range 19 to 61, mean age 29.3 years.
Study design:	Between-subjects.
Presence measures:	Igroup Presence Questionnaire (IPQ).
Findings:	(1) Type of movement had a significant effect on spatial presence and realness, with increased presence reported for self-movement, but had no significant effect on involvement. (2) Agents had no significant effect on any category of presence.

[Schubert, 2000 (2)] Schubert, T., H. Regenbrecht, and F. Friedmann. 2000. "Real and Illusory Interaction Enhance Presence in Virtual Environments." Submitted to *Presence 2000, 3rd International Workshop on Presence*. See also Regenbrecht (2002).

Factors:	Agent interaction (expected, not expected).
Computer platform:	SGI workstation.
Visual display:	Virtual Research VR4 HMD. Update rate ~15Hz. Participant standing.
Tracking:	Polhemus Fastrak for head tracking in self-movement condition.
Navigation:	Free movement in a circle 5m in diameter.
Object manipulation:	None.
Virtual world:	As in [Schubert, 2000 (1)] above.
Training:	Brief verbal description of the VE technology, especially the HMD, and the virtual world participants would experience. Additionally, participants were told they would see other characters in the virtual world. Half the participants were told these characters would react to the participant's actions, the others were told no interactions were possible.
Experimental task:	Count number of plates on the wall. 5 minute time limit.

Participants: 26 students; 4 males, 22 females; age range 15 to 41, mean age 24.6 years.
 Study design: Between-subjects.
 Presence measures: As in [Schubert, 2000 (1)] above.
 Findings: (1) Expectation of agent interaction had a significant positive effect on spatial presence only.

[Shim, 2001] Shim, W. and G.J. Kim. 2001. *Tuning of the Level of Presence (LOP)*. Pohang University of Science and Technology, Dept. of Computer Science and Engineering, Virtual Reality Laboratory. Pohang, Korea.

Factors: FOV (180°, 150°, 120°), detail (complex fish behaviors, simple fish behaviors).
 Computing platform: 3 Intel-Pentium III PCs with NVIDIA Quadro chipset-based graphic accelerator cards. Sense8's WorldToolKit, Release 9.
 Visual display: 3 wide-screen televisions/monitors.
 Tracking: No head tracking.
 Navigation: None.
 Object manipulation: None.
 Virtual world: Virtual fish tank with a few species of fish and seaweeds.
 Training: None.
 Experimental task: Observe and experience what it's like to be under the sea. 90 seconds for each of 6 trials.
 Participants: 23 graduate students; 20 males, 3 females; age range 19 to 27 years.
 Study design: Within-subjects.
 Presence measures: 8-item modified version of Witmer-Singer PQ.
 Findings: (1) FOV had a significant positive effect on presence, with a difference found between 180° and 120°.
 (2) Detail had a significant positive effect on presence, with increased presence reported for complex fish behaviors.

[Singer, 1998] Singer, M.J., J.A. Ehrlich, and R.C. Allen. August 1998. *Effect of a Body Model on Performance in a Virtual Environment Search Task*. Technical Report 1087. U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors: Self-representation (body model, pointer).
 Computing platform: SGI ONYX, with Performer and in-house software.
 Visual display: Virtual Research Corp. VR4 HMD with 742 × 230 color pixels/eye, FOV 48°H × 36°V. Participant eye height used to adjust display.
 Tracking: Head, shoulder, feet, right arm, and right hand using Ascension Flock of Birds.
 Object manipulation: In-house manufactured hand-held wand with button used to make target disappear.
 Virtual world: 12 different room configurations, rated as medium or low complexity. Typical office spaces and furniture. Three targets (briefcases) placed in each six-room trial set.
 Training: View videotape demonstrating moving and acquiring targets. Then guided through a locomotion and acquisition practice session in VE practice room.
 Experimental task: Search for briefcases hidden in office rooms. 6 trials.
 Participants: 32 participants; 18 males, 14 females; age range 18 to 44, mean age 22.5 years. Participants had 20/20 vision, low susceptibility to motion sickness, low scores on initial SSQ. Averaged 8 hours/week computer use. Four participants had prior VE experience.
 Presence measures: Witmer-Singer PQ.
 Person-related measures: Witmer-Singer ITQ, health, fitness, amount of sleep, medication use, experience with computers and VE.
 Task-related measures: Kennedy SSQ.

Performance measures: Number targets acquired, time to complete search, number of collisions. Also for each target room, time/collisions to visual acquisition of target, time/collisions to physical acquisition, time/collisions to exit.

Findings: (1) Self-representation had no significant effect on presence.
(2) Self-representation had no significant effect on the number of targets acquired, or any time/collision measures.

[Singer, 1997] Singer, M.J., R.C. Allen, D.P. McDonald, and J.P. Gildea. February 1997. *Terrain Appreciation in Virtual Environments: Spatial Knowledge Acquisition*. Technical Report 1056. U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors: Level of equipment (Hi-VE with head tracking, and treadmill movement control; Low-VE with no head tracking and joystick movement control; standard map training), level of detail (realistic, abstract terrain).

Computing platform: SGI Onyx. In-house software.

Visual display: VR4 HMD with 742 × 230 color pixels/eye, FOV 48° × 36°.

Tracking: Isotracks for head and hand tracking. Polhemus sensor strapped over 1st knuckle of the index finger for pointing.

Navigation: In the Hi-VE condition, using a treadmill where normal walking speeds were translated into a constant walking pace within the terrain database, movement in the direction of gaze. In the Low-VE condition, movement was controlled by Gravis 6DOF joystick and pointing.

Object manipulation: Pointing wand for indicating directions or locations and selecting objects.

Virtual world: Two terrains: (1) Abstract terrain derived from composite topographical maps; (2) Terrain developed from topographical map and aerial photography of 1km area east of the McKenna Military Operations in Urban Terrain, Ft. Benning.

Training: Topographical map training packet. Also, VE movement and control practiced using the VEPAB doorways and fixed tracking tasks, see [Singer, 1995] below.

Experimental task: Participants briefed on the terrain and path to be followed. While navigating terrain, at each of 3 checkpoints, participants locate several previously studied landmarks, identify 2 possible threatening terrain areas, and then cross the terrain following previously indicated route. Feedback on correct orientation and distance provided after each landmark identification, and information provided about the direction and distance to the next checkpoint.

Participants: 48 university students; 30 males and 18 females; age range 18 to 44, mean age 24.6 years. Participants met requirements for visual acuity, color vision, stereopsis. Participants passed a test of topographical map knowledge. Relatively VE-naive.

Study design: Between-subjects.

Presence measures: 32-item Witmer-Singer PQ Version 3.0.

Person-related measures: 34-item Witmer-Singer ITQ Version 3.0. *Also health, VE and computer experience, spatial abilities.*

Task-related measures: Kennedy SSQ, time spent in VE.

Performance measures: Spatial knowledge acquisition assessed by accuracy in pointing to landmarks from new positions in the terrain, and projective convergence to measure accuracy of cognitive map.

Findings: (1) Level of equipment and level of detail each had no significant effect on PQ Total or subscales.
(2) Time spent in the VE had a significant positive correlation with PQ Total and Involvement/Control subscale.
(3) ITQ Focus subscale had a significant positive correlation with PQ Total and Involved/Control and Naturalness subscales. ITQ Involvement had a significant negative correlation with PQ Interface Quality.
(4) SSQ Motion Sickness, Disorientation, and Oculomotor subscales had a significant negative correlation with PQ Interface Quality subscale.

- (5) Mean number of correct landmark directional identification, mean number of correct visually available landmark directional identification, mean correct identifications of individual landmarks, and mean percent of correctly identified visually available individual landmarks each had a significant positive correlation with PQ Involvement/Control subscale.
- (6) Average projective convergency measures of accuracy and consistency had a significant positive correlation with PQ Interface Quality.
- (7) *Fidelity and level of abstraction each had a significant effect on landmark identification pointing accuracy, with participants in the Hi-VE condition achieving more accuracy than those in the map condition.*
- (8) *Fidelity had no significant effect on accuracy and consistency of cognitive maps, but level of abstraction had a significant effect with improved performance found for the abstract map representation*
- (9) *Person-related measures (except for ITQ scores) had no significant correlation with spatial knowledge.*
- (10) *Fidelity and type of terrain each had a significant effect on only ITQ Total and Involvement subscale.*
- (11) *SSQ pre-experiment scales had a significant negative correlation with ITQ Focus and Disorientation subscales, and SSQ Oculomotor subscale had a significant positive correlation with ITQ Involvement. SSQ post-experiment scales had no significant correlation with ITQ subscales.*
- (12) *Mean correct identifications of individual landmarks, mean correct directional identifications of visually available landmarks, and mean correct directional identifications on non-visually available landmarks each had a significant positive correlation with ITQ Games subscale. No significant correlation with ITQ Total.*

[Singer, 1995] Singer, M.J., J. Ehrlich, S. Cinq-Mars, and J.-P. Papin. December 1995. *Task Performance in Virtual Environments: Stereoscopic Versus Monoscopic Displays and Head Coupling*. Technical Report 1034. U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors:	Stereopsis (present, absent), head tracking (present, absent).
Computing platform:	SGI Reality Engine. Sense8 software.
Visual display:	Flight Helmet HMD with 360 × 240 color pixels/eye, FOV 83°. IPD set for each participant. Participant remained seated.
Tracking:	Polhemus Isotrack for head tracking.
Navigation:	Movement controlled by 6DOF joystick.
Object manipulation:	Object selection, tracking, manipulation using 6DOF joystick.
Virtual world:	VEPAB worlds consisting of a series of simple VEs each focused on one task. No self-representation.
Experimental task:	VEPAB tasks: Doorways—move through 10 rooms with doors at various locations on the opposing walls. Bins—use a 3D crossed-line cursor to select a target ball in one of 9 bins and move it to a bin marked by an “X.” Fixed-tracking—place cursor on a stationary 0.7ft diameter ball-shaped target, where ball appears at locations 5 to 19.5ft away; target disappears after 20 seconds. Moving target—use cursor to track a ball that moves in a straight line with a randomly generated slope, target takes 13–19 seconds to traverse the room. Distance estimation—identify an object (soldier) starting at 40ft away and judge its height, then estimate when the object is 30, 20, 10, 5, 2.5ft away.
Participants:	48 participants; 36 males and 12 females; age range 18 to 50, mean age 23.6 years. Participants had normal or correct-to-normal vision (20/33 for near point acuity), no color vision deficiencies, good stereopsis, and no prior experience in VE research.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 2.0.
Person-related measures:	29-item Witmer-Singer ITQ, Hidden Figure Test for cognitive style.

Task-related measures: Kennedy SSQ.

Performance measures: Doorways—time to cross each room, number of collisions in each room. Bins—time to “grab” ball, total performance time, accuracy. Fixed target—percentage of total time cursor kept on target, time to first intercept. Moving target—percentage of total trial time during which cursor is kept on target, time to first intercept. Distance estimation—accuracy of distance judgments.

- Findings:
- (1) The interaction between stereopsis and head tracking had a significant effect on presence.
 - (2) ITQ Total had a significant positive correlation with PQ Total.
 - (3) SSQ Total and subscales had no significant correlation with PQ Total or subscales.
 - (4) Cognitive style had no significant correlation with any of PQ Total and subscales, and ITQ Total and subscales.
 - (5) Performance measures for the tasks each had no significant correlation with PQ Total or subscales.
 - (6) *Interaction of stereopsis and head tracking had a significant effect on ITQ Games subscale.*
 - (7) *Pre-test SSQ Oculomotor subscale had a significant positive correlation with ITQ Focus. Post-test SSQ total and Oculomotor subscale each had a significant negative correlation with ITQ Focus.*

[Slater, 2000a] Slater, M. 2000. “A Virtual Presence Counter.” *Presence*, 9(5), 413–434.

- Factors: Movement (reaching out to touch chess piece, mouse click).
- Computing platform: SGI Onyx with twin 196 MHz R10000, Infinite Reality Graphics and 64M main memory. Division dVS and dVISE 3.1.2 software.
- Visual display: Stereoscopic Virtual Reality VR4 HMD with 742 × 230 pixels/eye, 170,660 color elements, FOV 67° diagonal with 85° overlap. Frame rate ≥20Hz. Latency approximately 120ms.
- Tracking: Two Polhemus Fastraks for head and mouse tracking.
- Navigation: Moved in direction of gaze by pressing thumb button on mouse. Constant velocity.
- Object manipulation: Hand-held 5-button 3DOF mouse. Interaction with chess piece by either pressing a button on the 3D mouse or reaching out and ‘touching’ the object.
- Virtual world: Field connected to a virtual anteroom by a door. Field with trees and plants, and a 3D chessboard placed on a table positioned 5m from the door. Self-representation as simple inverse kinematic virtual body, with visible arm and hand. Total polygon count 13,298.
- Training: Provided in a virtual anteroom where shown how to move around, how to make a small red cube on a table respond by either touching it or clicking mouse button.
- Experimental task: Navigate through a door to outside scene and find 3D chessboard, find and select a specified chess piece, and observe a sequence of moves. Then press red button and, when sky turns dark, return from field to starting room.
- Participants: 20 university students and staff; 18 males, 2 females.
- Study design: Between-subjects.
- Presence measures: 5-item SUS questionnaire, breaks in presence.
- Findings:
- (1) Movement (taking hand movement into account) had a significant positive effect on breaks in presence measure for the active group only.
 - (2) Breaks in presence measure had a significant positive correlation with subjective presence.

[Slater, 2000b] Slater, M., A. Sadagic, M. Usoh, and R. Schroeder. 2000. “Small-Group Behavior in a Virtual and Real Environment: A Comparative Study.” *Presence*, 9(1), 37–51. See also Steed (1999), Tromp (1998).

Factors:	Visual display (HMD, desktop).
Computing platform:	SGI Onyx with twin 196 MHz R10000, Infinite Reality Graphics, and 64M main memory, running Irix 6.2. SGI High Impact system with 200 MHz R4400 and 64 MB main memory. SGI O2 running at 180 MHz on Irix 6.3 with a R5000 processor, and 32 MB main memory. DIVE 3.2 and RAT v.3.023 system.
Visual display:	Stereoscopic Virtual Reality VR4 HMD with 742×230 pixels/eye, 170,660 color elements, FOV 67° diagonal with 85° overlap. Frame rate ≥ 20 Hz. Latency approx. 120ms. 21-inch monitor, 17-inch monitor.
Tracking:	Two Polhemus Fastraks for tracking head and 3D mouse.
Navigation:	Immersive participant moved in direction of gaze at constant velocity by pressing button on 3D mouse. Desktop participants moved by using the keyboard arrow keys.
Object manipulation:	None.
Virtual world:	Model of actual laboratory where study took place. Includes a virtual room that had sheets of papers displayed around the walls. Each sheet had several words in a column, each preceded by a number. The words across all sheets with a common number combined to form a saying. Each participant represented by a basic DIVE avatar, differing only in color (red, green, blue), only visible to immersed (Red) participant. Approximately 3,500 polygons.
Training:	Learning to move through the environment.
Experimental task:	Group of 3 strangers meet in the VE and locate the room with puzzle. Figure out what puzzle is and then unscramble as many sayings as possible. One desktop participant (Green) was additionally tasked to monitor Red as closely as possible, always trying to be in Red's line of vision, moving temporarily when requested by Red. Leave the VE after about 15 minutes. Don jacket the same color as avatar and, after answering a 10-minute questionnaire, meet other participants outside the matching real room. Enter real room and continue task for about 15 minutes.
Participants:	10 groups of 3 participants recruited from a university campus. In each group, 1 participant immersed, 2 using desktop.
Study design:	Between-subjects.
Presence measures:	2-item SUS questionnaire, Slater's co-presence questionnaire.
<i>Person-related measures: Gender.</i>	
Task-related measures: Individual accord questionnaire, including 1 item on enjoyment and an overall rating of accord.	
<i>Performance measures: Number of riddles solved.</i>	
Findings:	<ol style="list-style-type: none"> (1) Visual display had no significant effect on presence. (2) Co-presence had a significant positive correlation with presence. (3) Individual accord had a significant positive correlation with combined and each of presence, co-presence. (4) <i>Number of riddles solved had a significant positive effect on individual accord.</i> (5) <i>Gender had a significant effect on individual accord, with females reporting increased accord.</i>

[Slater, 1999] Slater, M., D.-P. Pertaub, and A. Steed. 1999. "Public Speaking in Virtual Reality." *IEEE Computer Graphics and Applications*, 19(2), 6-9.

Factors:	Visual display (HMD, monitor), audience response type (positive, negative).
Computing platform:	SGI Onyx with twin 196 MHz R10000, Infinite Reality Graphics, and 192 Mbytes main memory. DIVE V3.3 software.
Visual display:	Stereoscopic VR4 HMD with 742×230 pixel resolution/eye, FOV 67° at 85° overlap, 170,660 color elements. Frame rate ≥ 10 Hz in stereo. Display lag ~ 100 ms.
Tracking:	2 Polhemus Fastraks for HMD and mouse.
Navigation:	Move in gaze direction at constant velocity when thumb pressed a button on hand-held 5-button 3DOF mouse.

Object manipulation: None.

Virtual world: Virtual seminar room populated with audience of 8 avatars seated in semicircle. Avatars continuously displayed scripted behaviors (with human operator directed timing) such as paying attention, clapping, talking to other audience members, head and body movements, and random behaviors such as twitching and blinking.

Experimental task: Practice a 5-minute talk with each of a positive and negative audience. Then give talk to an audience that started hostile and ended up positive.

Participants: 10 students and faculty members; 9 males, 1 female; age range 20 to 40 years.

Presence measures: 4-item Slater's co-presence questionnaire.

Person-related measures: Personal Report of Confidence as a Speaker, reported physical symptoms of anxiety.

Task-related measures: *Perceived audience interest rating.*

Performance measures: Self-rating of performance.

Findings: (1) Visual display had no significant effect on co-presence.
 (2) For monitor participants, self-rating of performance had a negative correlation with co-presence. For HMD participants, rating had a negative correlation for the negative audience and positive correlation for the positive audience.
 (3) *Perceived audience interest had a positive correlation with self-rating of performance for a negative audience only.*

[Slater, 1998] Slater, M., A. Steed, J. McCarthy, and F. Maringelli. 1998. "The Influence of Body Movement on Subjective Presence in Virtual Environments." *Human Factors*, 40(3), 469–477.

Factors: Movement (trees with large variation in height, low variation), task complexity (count number diseased plants, count and remember location of diseased plants).

Computing platform: SGI Onyx with twin 196 MHz R10000, Infinite Reality Graphics, and 64M main memory. Division dVS and dVISE 3.1.2 software.

Visual display: Stereoscopic VR4 HMD with 742 × 230 pixel resolution/eye, FOV 67° at 85° overlap, 170,660 color elements. Frame rate ≥ 10Hz in stereo. Display lag approx. 100ms.

Tracking: Polhemus Fastrak for HMD and mouse.

Navigation: Move in gaze direction at constant velocity when thumb pressed a button on hand-held 5-button 3DOF mouse.

Object manipulation: None.

Virtual world: Training lab connected via a door to a 90 × 75m field containing 150 plants or trees with large leaves, distributed randomly through the field. Each tree 2.4m across with 16 leaves. Healthy trees had green leaves, diseased trees had leaves (1 or 4) with brown underside. Trees were classed as healthy, trees with 1 bad leaf, or trees with 4 bad leaves, in equal proportion. Distribution of heights 1.7 ± 0.1m for low-variation field and 2.35 ± 1.9m for high-variation field. Self-representation as simple inverse kinematic virtual body. Total scene 32,576 triangles.

Training: Training tasks in a virtual lab matching real lab where experiment performed.

Experimental task: Simple task: move through field to count the number of diseased plants. Complex task: count number of diseased plants and remember where they were to later draw on a map. After about 3 minutes, sky brightened as a signal to start moving back to training lab.

Participants: 20 university students and staff, and journalist; 13 males, 7 females.

Study design: Between-subjects.

Presence measures: 6-item SUS questionnaire.

Person-related measures: Gender.

Task characteristics: Task complexity.

Findings: (1) Movement had a significant effect on reported presence, positive for head yaw, negative for extent of bending.

- (2) Task complexity and gender had no significant effect on presence individually, but there was a significant interaction between task complexity and gender, with females in the more complex task reporting lower presence than in the simpler task.

[Slater, 1996a] Slater, M., M. Usoh, V. Linakis, and R. Kooper. 1996a. "Immersion, Presence and Performance in Virtual Environments: An Experiment with Tri-Dimensional Chess." In *Proc. ACM Symposium on Virtual Reality and Technology (VRST '96)*, July 1–4, Hong Kong. 163–172.

Factors:	Visual display (HMD, desktop), scene realism (realistic setting with chess board in a garden setting, plain setting with chessboard suspended in void).
Computing platform:	Division ProVision 100 system. Board and chess pieces modeled in AutoCAD.
Visual display:	Stereoscopic, color Virtual Reality VR4 HMD with 360 × 240 pixels per eye (overall 704 × 480), FOV ~75°H × 40°V. Frame rate 15–20Hz.
Tracking:	Polhemus Fastrak for tracking hand and mouse.
Navigation:	Division 3D mouse. Forward movement accomplished by pressing a left thumb button, backward movement using a right thumb button.
Object manipulation:	Objects can be touched by virtual hand and grabbed using trigger button on mouse.
Virtual world:	3D chessboard placed on a table in a realistic garden setting (an open field also containing a chair, a tree, and small plant) with a sky dome, or suspended in a void. Self-representation as virtual hand. Garden texture mapped. Total garden scene 7,732 triangles, 6,276 in plain environment.
Training:	Introduction to 3D chess given in real world. Training in moving and selecting objects conducted in a VE similar to that used in the study.
Experimental task:	Initiate game by pressing red button near chessboard. When a chess piece changes color, touch this piece and watch its movement. Press red button again to repeat moves until confident can remember which pieces move and where they move to, and can later reproduce final state of the board on a real 3D chessboard.
Participants:	24 participants; 16 males and 8 females. Some with prior experience of VEs.
Study design:	Between-subjects.
Presence measures:	Multi-item questionnaire including 3 items related to presence.
Person-related measures:	Spatial Awareness Test. <i>Also gender, chess experience.</i>
Task-related measures:	<i>Practice, viewing time, level of nausea, confidence (that moves were remembered, correctly reproduced).</i>
Performance measures:	Number of correct moves.
Findings:	<ol style="list-style-type: none"> (1) Visual display had a significant effect on presence, with HMD users reporting more presence. (2) Scene realism had no significant effect on presence. (3) For immersed participants, the Spatial Awareness Test score had a significant negative relationship with presence. (4) Presence had no significant relationship with task performance. (5) <i>Visual display had a significant effect on performance, with improved performance found for the immersive display.</i> (6) <i>Scene realism had a significant effect on performance, with improved performance found for the realistic setting.</i> (7) <i>Chess experience and amount of virtual practice had significant positive effects on performance.</i> (8) <i>Gender had a significant effect on performance, with improved performance found for male participants. For females, Spatial Awareness Test score had a significant positive correlation with performance.</i>

[Slater, 1995a] Slater, M., M. Usoh, and A. Steed. 1995. "Taking Steps: The Influence of a Walking Technique on Presence in Virtual Reality." *ACM Transactions on Computer-Human Interaction*, 2(3), 201–219. See also Slater (1994a).

Factors:	Navigation (walking-in-place, 3D mouse).
Computing platform:	Division ProVision 200 system.
Visual display:	Stereoscopic, color Virtual Reality Flight Helmet with 360 × 240 pixels per eye, FOV 75°H. Frame rate ~15 fps.
Tracking:	Polhemus sensors for tracking head and mouse.
Navigation:	Movement by pressing a button on Division 3D mouse, with direction controlled by pointing or walking-in-place technique.
Object manipulation:	Division 3D mouse used for grasping objects by intersecting the virtual hand with an object and pulling the trigger button.
Virtual world:	A corridor with a door leading to a room containing a chasm over another room 20ft below, with a wide ledge around the room. Self-representation as virtual body.
Experimental task:	Pick up an object, take it into a room, and place it on a chair placed on the far side of a chasm.
Participants:	16 participants from university campus, with no prior experience of VE systems.
Study design:	Between-subjects.
Presence measures:	Multi-item questionnaire including 3 items related to presence. Observation of whether participants moved around the ledge or across chasm.
Task-related measures:	Rating of degree of nausea, extent of association with virtual body.
Findings:	<ol style="list-style-type: none"> (1) Navigation had a significant effect in that walking-in-place increased presence for participants who associated with their virtual body. (2) Path taken over chasm significantly associated with lower presence. (3) Reported nausea had a significant positive effect on presence.

[Slater, 1995b] Slater, M., M. Usoh, and Y. Chrysanthou. 1995. "The Influence of Dynamic Shadows on Presence in Immersive Virtual Environments." In *Proc. 2nd Eurographics Workshop on Virtual Reality*, January 31–February 1, Monte Carlo, 8–31.

Factors:	Dynamic shadows (shadows for red spears, no shadows).
Computing platform:	Division ProVision system with dVS Version 0.3, Gouraud shading.
Visual display:	Flight Helmet HMD with 360 × 240 pixels per eye, FOV 75° H. Frame rate without shadows 9Hz, with shadows 6–8Hz.
Audio display:	Real radio.
Tracking:	Head tracking.
Navigation:	Pressing center thumb button on Division 3D mouse for forward movement in direction of gaze.
Object manipulation:	Press left button on Division 3D mouse to fire a spear, spear moves in direction determined by hand orientation until button released (then spear cannot be reactivated). Press right button to act as "infra red" radio switch. Additional button used to select objects.
Virtual world:	Virtual room 10 × 6m. Five red spears near one wall, positioned with 10cm variation behind a screen. Virtual radio positioned immediately in front of screen. Red square on floor positioned 3m in front of screen. Four point light sources on wall facing red spears (used for dynamic shadows condition). Fixed target on wall at 90° to wall with red spears. Green spear that, without shadows, moves at mean velocity 92 cm/sec, with shadows at 47 cm/sec. Spears cast shadows that reflect their movement. Self-representation as virtual body. Total scene 413 triangles.
Training:	Practice run in VE with experimenter talking participant through experimental task.
Experimental task:	Move to red square and face red spears, and select spear nearest to wall. Move to selected spear, pick it up, return to red square, and turn to face target on far wall. Orient spear on target and launch spear, guiding it with hand movements. Stop

	spear the instant it reaches the target. Then take green spear to red square. Meanwhile, when radio starts, point to it and use “infra red” switch to turn it off.
Participants:	8 participants from a university campus.
Study design:	Within-subjects.
Presence measures:	6-item SUS questionnaire. Pointing to the position of a radio (switching on/off) when position of radio in real world differed from that in the virtual world.
Person-related measures:	Personal representation system (visual, auditory, kinesthetic) and perceptual position (exocentric, egocentric) neurolinguistic programming (NLP) assessment.
Performance measures:	Selection of correct spear, accuracy in estimating distance from target center and distance from wall.
Findings:	<p>(1) Dynamic shadows had a significant positive effect on presence, as measured by the reported and objective behavioral measures for participants dominant in the visual sense.</p> <p>(2) Reported presence had a significant positive correlation with objective behavioral measure of presence.</p> <p>(3) <i>Dynamic shadows had a significant effect only on distance to wall performance measure, with use of dynamic shadows resulting in less error.</i></p>

[Slater, 1995c] Slater, M., C. Alberto, and M. Usoh. 1995c. “In the Building or Through the Window? An Experimental Comparison of Immersive and Non-Immersive Walkthroughs.” In *Proc. Virtual Reality Environments in Architecture*, November 2–3, Leeds, UK. See also Usoh (1996).

Factors:	Visual display (HMD, desktop), color (VE matched to real location, matched to incorrect real location), elapsed time (same day visit to test building, 24 hours later).
Computing platform:	Division ProVision 100 system. VE modeled using AutoCAD.
Visual display:	Flight Helmet HMD with 360 × 240 pixels per eye, FOV 75° H. TV screen used for non-immersive condition (HMD placed on swivel chair in front of participant to use same method of setting viewpoint).
Tracking:	Polhemus Fastracks for tracking head and mouse.
Navigation:	Forward movement accomplished by pressing left thumb button on Division 3D mouse, backward movement by pressing right thumb button.
Object manipulation:	None.
Virtual world:	Representation of Computer Science Department in a building. Self-representation as 3D arrow cursor.
Training:	Participants were shown how to navigate through the virtual building.
Experimental task:	Search for a plant but only go through open doors. Then in a real building, visit 2 locations and select which matches the one in the VE. Then, in matching location, find the plant (in same location as in VE). Participants stayed in each type of environment for about 15 minutes.
Participants:	24 participants recruited from a university campus; 12 males, 12 females. Two had prior VE experience.
Study design:	Between-subjects.
Presence measures:	6-item SUS questionnaire. Additional question relating to “sense of having been there before.”
Person-related measures:	10-item NLP questionnaire.
Performance measures:	Time to find plant in VE and real building, accuracy of selection of matching locations in VE and real world.
Findings:	<p>(1) Visual display, color, and elapsed time each had no significant effect on presence.</p> <p>(2) Ratio of time to find plant in real world to time in virtual world had a negative correlation with presence for participant dominant in the auditory sense.</p> <p>(3) <i>Visual display, color, and elapsed time had no significant effect on either performance measure.</i></p>

[Slater, 1994b] Slater, M., M. Usoh, and A. Steed. 1994b. "Depth of Presence in Virtual Environments." *Presence*, 3(2), 130–144.

Factors:	Stacking type (transported between environments by donning virtual HMD, going through doors) and stacking depth (2, 4, 6), gravity (present, absent), virtual actor (following subject, staying in one position), visual cliff (present, absent).
Computing platform:	Division ProVision 200 system.
Visual display:	Virtual Reality Flight Helmet with resolution 360 × 240 pixels, FOV 75°H. Frame rate 7–16Hz. Subject standing, able to walk within range determined by trackers.
Tracking:	Polhemus sensors for head tracking and 3D mouse (sampling rate 30Hz).
Navigation:	Navigation by pressing middle button on Division 3D mouse, with direction determined by the direction in which the hand is pointed. Movement with constant velocity or a single small step can be made by a single button click.
Object manipulation:	Object selection using Division 3D mouse trigger.
Virtual world:	Initial scene consisting of empty room with cupboard and 12-inch cube. Subsequent scenes: (1) typical living room with sofas, table, TV; (2) abstract scene with randomly scattered cubes of difference sizes/colors; (3) typical office setting with desks, swivel chairs, computer, and filing cabinet; (4) kitchen with cupboards and cooker; (5) bar and bar furniture; (6) cliff with plank across a lower-level room with sofa, table, and chair. Self-representation as virtual body. Sound to mark transition between levels when using virtual HMD, also light touch on participant's back.
Training task:	In initial scene, practice how to move, pick up objects, and open cupboard doors for up to 5 minutes.
Experimental task:	Scenario based on a mixture of <i>Excalibur</i> and <i>Beauty and the Beast</i> . Task to find a set of swords, embedded in stone, hidden in the environment, and pull out the 1 sword that could be moved. Find a nearby well and drop the sword down it. The Beast was awakened when the correct sword was found.
Participants:	23 participants from a university campus.
Study design:	Between-subjects.
Presence measures:	Multi-item questionnaire with 3 items relating to presence. Observation of whether participant moved real body to match virtual body.
Person-related measures:	11-item NLP questionnaire.
Findings:	(1) Stacking depth had a significant effect on presence, with a positive relationship when using a HMD and negative when transported via doors. (2) Focus on visual or kinesthetic representation systems had a significant positive association with presence, focus on auditory representation system had a significant negative association with presence. (3) Gravity, virtual actor, or visual cliff had no significant effect on presence. (4) Aligning real and virtual bodies had no significant correlation with subjective presence.

[Slater, 1993a] Slater, M. and M. Usoh. 1993a. "The Influence of a Virtual Body on Presence in Immersive Virtual Environments." In *Proc. 3rd Annual Conference on Virtual Reality*, 34–42. See also Slater (1993b, 1993c, 1992).

Factors:	Self-representation (virtual body, arrow cursor).
Computing platform:	Division ProVision 200 system.
Visual display:	Flight Helmet HMD with 360 × 240 pixels per eye, FOV 100°H × 60°V. Frame rate 8–16 fps.
Audio display:	HMD headphones.
Tracking:	Two Ascension Technologies Flock of Birds used for tracking of head and mouse.

Navigation:	Forward movement accomplished by pressing left thumb button on Division 3D mouse, backward movement by pressing right thumb button. Move in direction of pointing.
Object manipulation:	Selection of objects using mouse trigger.
Virtual world:	Corridor showing 6 doors on the left-hand side. A cube was positioned in the middle of the corridor. Room 1 contained everyday objects that might be found in an office. Room 2 contained various objects that would fly towards the subject at body level. Room 3 held a set of different colored blocks. Room 4 contained objects that would fly toward the subject's face. In Room 5, standard floor and ceiling patterns (and the virtual body when present) were reversed. Room 6 consisted of a chessboard with 2 pieces and a plank over a chasm that contained another chess board about 18ft below. Sound cues when an object is grabbed, or a door opens.
Training:	Once in VE, told how to operate navigation controls. Then instructed to walk to far end of corridor, then back to cube and instructed how to pick it up. Move cube around and drop it.
Experimental task:	Visit each room. In Room 1, navigate to the other side of the room, stop, and then return back to corridor. In Room 3, build a pile using all the blocks. In Room 6, pick up a chess piece and drop it over the edge of the plank onto the lower chessboard. Total time ranged from 13 to 27 minutes.
Participants:	17 graduate students studying human computer interaction.
Study design:	Between-subjects.
Presence measures:	6-item SUS questionnaire. Observation of reaction to situations of relative danger.
Person-related measures:	NLP assessment. Self-rating of adaptation to new environments.
Task-related measures:	Loss of realism as indicated in responses to open-ended questions.
Findings:	<ol style="list-style-type: none"> (1) Self-representation had a significant positive effect on reported presence, with increased presence reported for a virtual body. (2) Focus on visual senses significantly positively associated with increased presence, focus on auditory senses negatively associated with presence. (3) For participants with a virtual body, focus on kinesthetic senses significantly positively associated with presence. For those without a body, focus on kinesthetic senses negatively associated with presence. (4) Participants who mentioned problems with a loss of realism (things don't behave realistically) had significantly lower presence. (5) Considered separately, each of reaction to height and reaction to flying objects had no relationship with subjective presence, but a reaction to either was more likely to occur for a lower sense of presence. (6) Participants self-rated as fast adapters to new environments reported a lesser sense of presence.

[Snow, 1996 (1)] Snow, M.P. December 1996. *Charting Presence in Virtual Environments and Its Effects on Performance*. Ph.D. Dissertation, Virginia Polytechnic and State University. VA. See also Snow (1998).

Factors:	Update rate (8, 12, 16Hz), display resolution (320 × 200, 640 × 480), FOV (48°H × 36°V, 36°H × 27°V, 24°H × 18°V).
Computing platform:	2 Pentium PCs, Superscape VRT software with collision modeling.
Visual display:	Monoscopic VR4 HMD with FOV and resolution varying across experimental conditions. Viewpoint and eye level set at participant's standing eye level. Viewpoint attached to invisible body that measured 16.5 inches front-to-back and side-to-side. Participants standing at a swiveling platform.
Audio display:	HMD headphones.
Tracking:	Ascension Technologies Flock of Birds for head tracking.
Navigation:	Logitech Magellan 6DOF control device (3DOFs disabled) resting on platform.

Object manipulation:	Standard mouse resting on platform, and left-click to interact with objects beneath the cursor.
Virtual world:	Rooms connected by corridors with left- and right-turns and an elevator. Floors with checkerboard pattern, walls 8ft high with narrow vertical stripes every 5ft, ceilings with horizontal light panels every 10ft, corridors 3ft wide. One room with desk, chair, filing cabinets, wall-mounted vertical rack of open bins, clock on wall, 2 other rooms with fewer objects. Self-representation as arrow cursor. No texture mapping.
Training:	Pen-and-paper practice in magnitude estimation. Guided walk-through and demonstration of each task. One practice trial for each task.
Experimental task:	5 tasks: distance estimation of moving target (40 feet and less), bins task, moving through corridors, detect moving target, choose static target. Average total time 2.5 hours.
Participants:	12 participants; age range 16 to 42, mean age 22 years. Participants had normal visual acuity, normal color vision, normal stereo acuity.
Study design:	Within-subjects.
Presence measures:	Magnitude estimation as ratio-scale measure of presence.
Task-related measures:	Time spent in VE.
Performance measures:	Locomotion time to complete and number of errors, distance estimation accuracy, bins task response time, moving target response time, choice response time.
Findings:	<ol style="list-style-type: none"> (1) Update rate, display resolution, and FOV each had a significant positive effect on presence. (2) Time spent in VE had a significant effect on presence (positive or negative not specified). (3) Time to complete and errors made in turns task, and time to complete search task had a significant negative correlation with presence, but time to complete bins task and time to complete choice task had no significant correlation. (4) <i>Update rate had a significant negative effect on time to complete turns task and choice performance, but no significant effect on each of distance estimation accuracy, time to complete Bins task, errors made during Turns task, and search performance.</i> (5) <i>Display resolution had a significant negative effect on distance estimation accuracy and search performance, but no significant effect on each of time to complete Bins task, errors made during Turns task, time to complete Turns task, and choice performance. The interaction between display resolution and FOV had a significant effect on search performance.</i> (6) <i>FOV had a significant negative effect on distance estimation accuracy and search performance, but no significant effect on each of time to complete Bins task, errors made during Turns task, time to complete Turns task, and choice performance.</i>

[Snow, 1996 (2)] Snow, M.P. December 1996. *Charting Presence in Virtual Environments and Its Effects on Performance*. Ph.D. Dissertation, Virginia Polytechnic and State University. VA. See also Snow (1998).

Factors:	Audio cues (auditory feedback when subject bumped into objects and clicked on interacting objects, and context-appropriate sounds; none), texture mapping (textures applied to doors, walls, bins, and other objects; none), head tracking (present, absent), stereopsis (present, absent), virtual personal risk (rear elevator doors missing, doors present).
Computing platform...	Performance measures: As in [Snow, 1996 (1)] above, except Visual Display employed FOV 48°H × 36°V, resolution 640 × 480; and update rate fixed at 8Hz.
Findings:	<ol style="list-style-type: none"> (1) Sound, texture mapping, head tracking, and stereopsis each had a significant positive effect on presence. (2) Virtual personal risk and time spent in VE had no significant effect on presence.

- (3) *Errors made in locomotion task had a significant negative correlation with presence, but time to complete each of the bins, turns, search, and choice tasks had no significant correlation.*
- (4) *Audio cues had no significant effect on each of distance estimation, time to complete bins task, time to complete turns task, time to complete search task, and choice performance.*
- (5) *Texture mapping had a significant effect on distance estimation, but no significant effect on each of time to complete bins task, errors in turns task, time to complete turns task, time to complete search task, and choice performance. An interaction between audio cues and texture mapping also had a significant effect on errors in turns task.*
- (6) *Head tracking had a significant effect on errors in turns task, time to complete turns task, and time to complete search task, but no significant effect on each of distance estimation, time to complete bins task, and choice performance. An interaction between texture mapping and head tracking also had a significant effect on time to complete bins task.*
- (7) *Stereopsis had a significant effect on distance estimation, but no significant effect on each of time to complete bins task, errors in turns task, time to complete turns task, time to complete search task, and choice performance. An interaction between audio cues and stereopsis also had a significant effect on each of distance estimation and time to complete bins task.*
- (8) *Virtual personal risk had a significant effect on errors in turns task and time to complete search task, but no significant effect on each of distance estimation, time to complete bins task, time to complete turns task, and choice performance.*

[Snow, 1996 (3)] Snow, M.P. December 1996. *Charting Presence in Virtual Environments and Its Effects on Performance*. Ph.D. Dissertation, Virginia Polytechnic and State University. VA.

Factors: Level of interaction (6, 12, 18 interactions possible), second user (present, absent), detail (low, medium, high).

Computing platform...Performance measures: As in [Snow, 1996 (2)] above.

- Findings:
- (1) Level of interactions possible and level of detail had no significant effect on presence separately, but a significant interaction effect.
 - (2) Second user had a significant positive effect on presence, as did the interaction between environmental detail and number of interactions.
 - (3) Time in VE had a significant effect on presence.
 - (4) Time to complete each of bins, turns, and search tasks and errors made in turns task each had a significant negative correlation with presence, but time to complete the choice task had no significant correlation.
 - (5) *Level of interaction, second user, and level of detail each had no significant effect on any performance measure.*

[Steed, 1999] Steed, A., M. Slater, A. Sadagic, A. Bullock, and J. Tromp. 1999. "Leadership and Collaboration in Shared Virtual Environments." In *Proc. IEEE Annual Virtual Reality Inter. Symposium*, March 13–17, Houston, TX.

Factors: Visual display (HMD, desktop).

Computing platform: SGI Onyx with twin 196 MHz R10000, Infinite Reality Graphics, and 192M main memory. SGI Indigo with a 200 MHz R4400 processor, High Impact graphics, 192M main memory. SGI Octane with a 195 MHz R10000, 128M main memory. dVS and audio server. ISDN connection. Dive 3.2 software.

Visual display: Virtual Research VR4. Two desktop monitors.

Tracking: Two Polhemus Fastraks for tracking HMD and 3D mouse.

Navigation:	Immersive participant moved in direction of gaze at constant velocity by pressing button on 3D mouse with 5 buttons. Desktop participants moved using a standard mouse with 3 buttons.
Virtual world:	Model of actual laboratory where study took place. Includes a virtual room that had sheets of papers displayed around the walls. Each sheet had several words in a column, each preceded by a number. The words across all sheets with a common number combined to form a saying. Each participant represented by a basic DIVE avatar, differing only in color (red, green, blue), only visible to immersed (Red) participant.
Training:	Learning to move through the environment. 4–5 minutes.
Experimental task:	Group of 3 strangers meet in the VE and locate the room with puzzle. Figure out what puzzle is and then unscramble as many sayings as possible. 15 minute time limit. Don jacket the same color as avatar and, after answering a 10-minute questionnaire, meet other participants outside the matching real room. Enter real room and continue task for about 15 minutes.
Participants:	20 groups of 3 participants (data unavailable for 8 of these participants).
Study design:	Between-subjects.
Presence measures:	6-item SUS questionnaire, Steed's co-presence questionnaire.
Task-related measures:	7-item accord questionnaire.
Findings:	<ol style="list-style-type: none"> (1) Visual display had no significant effect on presence and co-presence. (2) Presence had a significant positive relationship with co-presence. (3) Accord had a significant positive relationship with co-presence.

[Stevens, 2002] Stevens, B., J. Jerrams-Smith, D. Heathcote, and D. Callear. 2002. *Putting the Virtual into Reality: Assessing Object-Presence with Projection-Augmented Models*. Dept. Information Systems, University of Portsmouth. UK.

Computing platform:	PC with 166 MHz Pentium processor, 40 MB RAM.
Visual display:	3M MP8725 LCD projector, 800 × 600 resolution, 52 × 38cm total image array projected on an A1 sheet of white paper. Participants seated in darkened room.
Audio display:	None.
Navigation:	Standard mouse.
Object manipulation:	Standard mouse.
Projected model:	Microsoft Paint. Physical model consisted of a white, plaster-covered polystyrene representation of a mobile telephone approx. 4x size of conventional mobile phone.
Training:	3-minute practice task using the drawing package projected onto a flat white surface.
Experimental task:	Design a color scheme for a mobile telephone case, directly on the model's surface. 15 minute time limit.
Participants:	16 participants; 8 male, 8 female; age range 22 to 39, mean age 29 years. Computer literate but without experience in drawing packages.
Presence measures:	Object Presence Questionnaire (OPQ).
Person-related measures:	Witmer-Singer ITQ, age, gender, drawing application competency, design type.
Task-related measures:	Task completion time.
Findings:	<ol style="list-style-type: none"> (1) Task completion time had no significant correlation with OPQ Total or any OPQ subscales (2) Total ITQ scores had no significant correlation with OPQ scores. For males, ITQ Focus subscale had a significant positive correlation with OPQ Total and Involvement/Control and Natural subscales; and ITQ Involvement subscale had a significant positive correlation with OPQ Involvement/Control subscale. For females, ITQ total and Games subscale each had a significant negative correlation with OPQ Natural subscale; and ITQ Involvement subscale had a significant negative correlation with OPQ Involvement/Control. (3) Age, gender, drawing application competency, and design type had no significant correlation with OPQ Total or any OPQ subscales.

- (4) Age and gender each had a significant correlation with ITQ Games subscale only. Drawing application competency, and design type each had no significant correlation with ITQ total or any ITQ subscales.
- (5) Task completion time had no significant correlation with ITQ total or any ITQ subscales.

[Thie, 1998] Thie, S. and J. van Wijk. 1998. "A General Theory on Presence." In *Proc. 1st Inter. Workshop on Presence*, Ipswich, UK. Available at <http://www.cs.ucl.ac.uk/staff/m.slater/BTWorkshop/KPN/>.

Factors: Social presence manipulation (choose avatar, choose nickname, personal information provided, trace other participants, gestures, moderator, know who said/did what, 3-person audio connection; none).

Computing platform: 4 multimedia PCs running NT and Win '95. Software included Netscape Navigator 3.01, Blaxxun Cyberhub, and Passport multi-user clients/servers.

Visual display: Desktop monitors.

Object manipulation: None.

Virtual world: Shared VE.

Training: Practice with the SVE.

Experimental task: Decision making tasks.

Participants: 48 participants; 24 males, 24 females. All experienced in browsing the Internet, no prior experience with similar experiment.

Study design: Between-subjects.

Presence measures: Psotka's 21-item virtual presence and Thie's social presence questionnaires, extremity of decision made, come-back rate.

Person-related measures: Psotka's 15-item Susceptibility for Presence Questionnaire.

Findings: (1) Social presence manipulation had no significant effect on social or virtual presence or extremity of decision making, but did significantly increase come-back rate.
 (2) Social virtual presence had a significant positive correlation with virtual presence.
 (3) Come-back rate had a significant positive correlation with virtual presence, but no significant relationship with social virtual presence.
 (4) Susceptibility for presence had no significant correlation with virtual presence.

[Tromp, 1998 (2)] Tromp, J., A. Bullock, A. Steed, A. Sadagic, M. Slater, and E. Frecon. 1998. "Small Group Behavior Experiments in the Coven Project." *IEEE Computer Graphics*, 18(6), 53–63. See also Steed (1999).

Factors: Avatar realism (realistic, basic).

Computing platform: UCL machines SGI Onyx with twin 196 MHz R10000 processors, Infinite Reality graphics, 192M of main memory; SGI Indigo with a 200 MHz R4400 processor and 64M main memory; audio server. Nottingham machine SGI Indigo with a 200-MHz R4400 processor, High Impact graphics, 192M main memory. IIS machine SGI Octane with a 195 MHz R10000 and 128M main memory. dVS/dVISE 5.0 and RAT software. ISDN connections with mean round trip times overall all trials being 100ms between Nottingham and UCL, 450ms between Nottingham and IIS, and 300ms between UCL and IIS.

Visual display: Virtual Research VR4, resolution 742 × 230 pixels/eye, FOV 67° diagonal, with 85% overlap, 170,660 color elements. 2 desktop monitors with 21-inch screen. Frame rate 20–30Hz on all machines. Latency ~120 ms.

Tracking: Polhemus Fastraks for head and mouse tracking.

Navigation: 5-button mouse or keyboard arrow keys.

Object manipulation: None.

Virtual world...Experimental task: See [Slater, 2000b] above.

Participants: 4 groups of 3 participants from a university campus. In each group, 1 participant immersed, 2 using desktop monitors.

Study design: Between-subjects.

Presence measures: Tromp's questionnaire, Slater's co-presence questionnaire.

Task-related measures: Ratings of group as a whole on accord.

Findings: (1) Avatar realism had no significant effect on presence.
 (2) Co-presence had no significant correlation with presence.
 (3) Group accord had a significant positive correlation with co-presence, but no significant correlation with presence.

[Uno, 1997] Uno, S. and M. Slater. 1997. "The Sensitivity of Presence to Collision Response." In *Proc. IEEE 1997 Virtual Reality Annual International Symposium*, March 1–5, Albuquerque, New Mexico. 95–103.

Factors: Collision response where realism of collisions manipulated using elasticity (1.0, 0.7), friction (0.7, 0.0), shape (ellipsoid, true shape).

Computing platform: Division ProVision100.

Visual display: Virtual Research Flight Helmet HMD, with 360 × 240 pixel resolution/eye, FOV 75°H × 40°V.

Tracking: Polhemus Fastrak for head and mouse tracking.

Navigation: Move by pressing button on Division 3D mouse.

Object manipulation: Objects grabbed using trigger button on 3D mouse.

Virtual world: Self-representation as virtual hand.

Experimental task: Two games of pin bowling, with one collision parameter changed between games.

Participants: 18 students, research workers, and other college staff; 12 males, 6 females.

Presence measures: 6-item SUS questionnaire.

Person-related measures: Prior experience of VR.

Task-related measures: 1 question on experience of dizziness, sickness, or nausea.

Findings: (1) Elasticity and shape had no significant effect on presence. Friction had a significant effect, positive with correct shape and negative with elasticity.
 (2) Prior VR experience had a significant negative effect on presence.
 (3) Simulator sickness had a significant negative effect on presence.

[Usuh, 2000] Usuh, M., E. Catena, S. Arman, and M. Slater. 2000. "Using Presence Questionnaires in Reality." *Presence*, 9(5), 497–503.

Factors: Environment type (virtual, real).

Computing platform: SGI Onyx with twin 196 MHz R10000, Infinite Reality Graphics, 192M main memory.

Visual display: VR4 HMD with resolution of 742 × 230 pixels per eye, FOV 67°D at 85% overlap, 170,660 color elements. Frame rate ≥20Hz. Latency ~120ms.

Tracking: Two Polhemus Fastraks for tracking head and mouse.

Navigation: Move through environment in direction of gaze while pressing thumb button on 5-button, 3D mouse.

Object manipulation: None.

Virtual world: University research lab. Total scene 12,564 polygons.

Experimental task: Search for a red box hidden in an office space. 7–14 minutes in the virtual office, 6–10 minutes in the real office.

Participants: 20 university students; 15 males, 5 females.

Study design: Between-subjects.

Presence measures: 32-item Witmer-Singer PQ Version 2.0, 6-item SUS questionnaire.

Task-related measures: Subjective rating of task performance.

Performance measures: Time to complete task.

- Findings:
- (1) Environment type had no significant effect on PQ and SUS presence totals, but had a significant effect on 2 items on SUS questionnaire, with users of the real environment reporting more presence.
 - (2) SUS questionnaire scores had no significant correlation with PQ Total scores for the virtual world, but did have a significant positive correlation for the real world condition.
 - (3) Task performance had no significant correlation with either Witmer-Singer PQ scores or SUS questionnaire scores.
 - (4) Self-rating of task performance had no significant correlation with SUS questionnaire and PQ scores.

[Usuh, 1999] Usuh, M.K.A., M.C. Whitton, R. Bastos, A. Steed, M. Slater, and F.P. Brooks Jr. 1999. "Walking > Walking-in-Place > Flying, in Virtual Environments." In *Proc. Computer Graphics Annual Conference*, Los Angeles, CA. 359–364.

- Factors: Navigation (walking-in-place, push-button-fly, real walking).
- Computing platform: SGI Onyx2 with 1 graphic pipe, 4 195 MHz R10000 processors, 2GB main memory. Scene rendered using Open GL and locally developed software.
- Visual display: Virtual Research V8 HMD with (640x3) × 480 pixels per eye, FOV 60°D at 100% overlap, aspect ratio 4:3. Radiosity lighting, texturing for half the polygons. Frame rate 30Hz stereo. Overall system latency 100ms.
- Tracking: Custom optical wide area tracking, 10 × 4m, latency 25ms, head and one hand.
- Navigation: For push-button-fly, used a joystick with locomotion in direction of gaze. Lag 500ms for walking-in-place.
- Object manipulation: Using joystick.
- Virtual world: 5 × 4m training room and 5 × 4m pit room, connected by a door. Training room contained some chairs, a blue box, a green box. Pit room has 0.7m ledge 6m above the floor of the room, with a chair positioned on the ledge on the side of room opposite the door. Floor below populated with living room furniture. Self-representation as virtual body. Total 40,000 polygons.
- Training: Participants practiced locomotion and picking up the blue box until they felt comfortable with both.
- Experimental task: Pick up green box in training room and carry it to the chair in the pit room.
- Participants: 44 participants; 28 males, 26 females. 11 participants had VE prior experience.
- Study design: Between-subjects.
- Presence measures: Presence questionnaire augmented with questions on awareness of background noises, similarity of pit reaction to real world reaction, extent of vertigo/fear of falling, willingness to walk out over the pit, path taken to chair on other side of pit.
- Person-related measures Game playing experience.
- Task-related measures: Degree of associated with virtual body.
- Findings:
- (1) Navigation had a significant effect on reported presence, with real walkers reporting more presence than walking-in-place users, who reported more presence than push-button-fliers. When oculomotor discomfort is considered, there was no significant difference between real walking and walking-in-place, but these groups reported significantly more presence than push-button-fliers.
 - (2) Navigation had no significant effect on behavioral measures of presence.
 - (3) Degree of association with virtual body had a significant positive relationship with reported and behavioral presence.
 - (4) Reported presence had a significant positive correlation with behavioral measures of presence.
 - (5) Game playing had a significant negative relationship with reported presence, but had no significant correlation with behavioral presence.
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[Usoh, 1996] Usoh, M., C. Alberto, and M. Slater, 1996. *Presence: Experiments in the Psychology of Virtual Environments*. Department of Computer Science, University College London. UK.

Factors: Detail (realistic with colored and textured objects, monochrome objects with no texture), agents (people standing by desks, no people).
Computing platform: Division ProVision 100 system.
Visual display: Flight Helmet HMD with 360×240 pixels per eye, FOV 75° H.
Tracking: Head tracking.
Navigation: Using mouse.
Object manipulation: Touching computer with virtual hand.
Virtual world: Laboratory in Computer Science Department (Room V127). Included accurate representation of color and placement of desks, chairs, computers, cabinets, and floor space. Virtual people in the form of cardboard cut-outs.
Training: Familiarization with virtual world by navigating through it.
Experimental task: Move through virtual world and switch on 6 computers, being automatically transported back to starting position after each computer switched on. Then go back and touch computers previously switched on (without being transported after each touch).
Participants: 16 participants, university staff and students. 8 had desks in Room V127, 8 participants were unfamiliar with Room V127.
Study design: Between-subjects.
Presence measures: Multi-item questionnaire including 3 items related to presence. Observation of socially-conditioned behaviors and conventions.
Person-related measures: NLP assessment.
Findings: (1) Level of detail and agents each had no significant effect on observed behavior.
(2) For participants unfamiliar with Room V127, auditory representation mode had a significant negative correlation with presence.

[Welch, 1999] Welch, R.B. 1999. "How Can We Determine if the Sense of Presence Affects Task Performance?" *Presence*, 8(5), 574–577.

Factors: Audio cues (screeching of tires, no cues).
Visual display: HMD.
Experimental task: Control a virtual car and attempt to collide with various cubes while avoiding others.
Study design: Within-subjects.
Presence measures: Presence-rating scale (1–100%).
Performance measures: Number of collisions with cubes in a fixed period of time.
Findings: (1) Audio cues had a significant effect on presence, with more presence reported for use of tire sounds.
(2) Audio cues had no significant effect on task performance.

[Welch, 1996 (1)] Welch, R.B., T.T. Blackmon, A. Liu, B.A. Mellers, and L.W. Stark. 1996. "The Effects of Pictorial Realism, Delay of Visual Feedback, and Observer Interactivity on the Subjective Sense of Presence." *Presence*, 5(3), 263–273.

Factors: Scene realism (high scene detail, low scene detail), level of interaction (driver, passenger).
Computing platform: SGI 4D/120 GTXB graphics workstation.
Visual display: Monitor with horizontal GFOV 62.5° , 1280×1024 pixels, stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses. Nominal IPD 6.5cm. Subject seated with viewing distance of 0.75m, FOV $\sim 27^\circ$. Curtain drawn around subject for isolation from rest of laboratory.

Navigation: Steering wheel and foot-operated accelerator and brake pedals to control the car's direction and speed.

Object manipulation: None.

Virtual world: In high realism condition, blue sky, hilly road surface and surround, green background, red farm houses, oncoming cars, and guard posts. In low realism condition, black sky, flat road surface and surround, black background, no peripheral objects, no oncoming cars.

Training: Two pairs of practice runs.

Experimental task: Drive a simulated car as quickly and smoothly as possible through a lap of a winding road. When passenger instead of driver, count number of oncoming cars.

Participants: 20 optometry students, laboratory staff, and engineering graduate students; 9 males, 11 females; mean age 27.2 years.

Study design: Within-subjects.

Presence measures: Paired comparison with rating of difference.

Findings: (1) Scene realism and level of interaction each had a significant effect on presence, with more presence reported for the high scene detail/driver condition than for the low scene detail/passenger condition.

[Welch, 1996 (2)] Welch, R.B., T.T. Blackmon, A. Liu, B.A. Mellers, and L.W. Stark. 1996. "The Effects of Pictorial Realism, Delay of Visual Feedback, and Observer Interactivity on the Subjective Sense of Presence." *Presence*, 5(3), 263–273.

Factors: Scene realism (high scene detail, low scene detail), latency (no additional delay, additional 1.5 sec delay in visual feedback). (Standard delay 200–220msec.)

Visual display... Presence measures: As in [Welch, 1996 (1)] above; except for Participants: 20 optometry students, laboratory staff, engineering graduate students; 9 males, 11 females; mean age 23.4 years.

Findings: (1) Scene realism and latency each had a significant effect on presence, with more presence reported for high scene detail/no additional delay condition than for the low scene detail/additional delay condition.

[Whitelock, 2000] Whitelock, D., D. Romano, A. Jelfs, and P. Brna. October 2000. *Perfect Presence: What Does This Mean for the Design of Virtual Learning Environments?* PLUM Paper No. 137. Institute of Educational Technology, Open University, Milton Keynes. UK. See also <http://www.presence-research.org/Whitelock&Jelfs.html>.

Factors: Audio cues (present, absent), type of training (video, written script).

Computing platform: PC-based. MTropolis software.

Visual display: Desktop monitor showing 2 views: one from submarine, other plan view showing where submarine located.

Navigation: Standard mouse used to move the submarine.

Virtual world: Representation of the North Atlantic Ridge. Supported with movies of geological features, flora, and fauna that illustrate probe functions.

Training: Either viewed prerecorded video of using application, or read script containing same instructions used in the video. 30 minute time limit.

Experimental task: Travel in submarine to the Ridge at the bottom of the ocean and explore the terrain for geological structures and biological life in seven major locations. 30 minute time limit.

Participants: 10 pairs of high school students; age range 16 to 17 years.

Study design: Between-subjects.

Presence measures: Romano's questionnaire.

Person-related measures: *Computing and game playing experience*.

Task-related measures: Rating of ease of task.

Performance measures: Pre- and post-test of learning.

- Findings:
- (1) Enhanced audio cues had a positive effect on presence.
 - (2) Ease of task had a positive correlation with presence.
 - (3) *Audio cues had no significant effect on conceptual learning.*
 - (4) *Type of training had no significant effect on performance.*
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[Wideström, 2000] Wideström, J., A.-S. Axelsson, R. Shroeder, A. Nilsson, Å. Aebelin. 2000. "The Collaborative Cube Puzzle: A Comparison of Virtual and Real Environments." In *Proc. ACM Conference on Collaborative Virtual Environments*, San Francisco, CA. 165–171.

- Factors: Environment type (real, Cave display, desktop).
- Computing platform: SGI Onyx2 Infinite Reality with 14 MIPS R10000 processors, 250 MHz, 2 GB RAM, 3 graphics pipes. SGI O2 with 1 MIPS R10000 processor, 256 MB RAM. DVise 6.0 software with SGI Performer renderer. Lake Huron 3.0 for audio.
- Visual display: 3 × 3 × 3m TAN 3D Cube with projection on 5 walls (no ceiling), stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses; frame rate at least 30Hz. 19-inch monitor with frame rate at least 20Hz.
- Auditory display: Using headsets.
- Tracking: Polhemus trackers attached to shutter glasses and hand.
- Navigation: In the Cave system: by moving around and gesturing with DVise 3D mouse. In the desktop system: by moving middle button on standard 2D mouse.
- Object manipulation: In the Cave system: blocks selected and moved by participant putting his hand into a virtual cube and pressing on a 3D mouse button. In the desktop system: blocks selected by clicking on the block with the left button of 2D mouse, then moved by keeping right button pressed and moving the mouse; cubes rotated using a combination of the right mouse button and shift key.
- Virtual world: Empty room containing 8 blocks with 1 of 6 different colors on each side. Representation of self and participant using standard dVise avatars.
- Experimental task: Two participants cooperate to solve a puzzle by arranging blocks into a cube such that each side of the completed cube displays a single color. 20 minute time limit.
- Participants: 44 pairs of participants; 53 males, 35 females; age range 20 to 56, mean age 32 years.
- Study design: Within-subjects.
- Presence measures: Wideström's presence and co-presence questionnaires.
- Task-related measures: 3-item contribution to task questionnaire, 1 item on collaboration.*
- Findings:
- (1) Environment type had a significant effect on presence, with participants in the Cube reporting more presence.
 - (2) Environment type had no significant effect on co-presence.
 - (3) Presence had a significant correlation with co-presence only in the desktop environment.
 - (4) *Environment type had a significant effect on all contribution to task items, with higher contribution assigned to Cave display participant by both participants.*
 - (5) *Environment type had no significant effect on rating of collaboration, with significantly more collaboration reported for the real environment than virtual environments. Cave display and desktop conditions had no significant difference.*
 - (6) *There was a significant order effect on collaboration score, such that participants with experience from the virtual task reported significantly more collaboration in the real world than in the virtual world, while there was no difference for participants who started with the real task and then performed the virtual task.*
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[Wiederhold, 2001] Wiederhold, B.K., D.P. Jang, M. Kaneda, I. Cabral, Y. Lurie, T. May, I.Y. Kim, M.D. Wiederhold, and S.I. Kim. 2002. "An Investigation into Physiological Responses in Virtual Environments:

An Objective Measurement of Presence.” In G. Riva & C. Galimberti (Eds.), *Towards CyberPsychology: Mind, Cognitions and Society in the Internet Age*. Amsterdam: IOS Press.

Computing platform: Intel microprocessor-based PC, with advanced audio and Diamond Monster-3D graphics cards. Customized software.

Visual display: Liquid Image MRG4 HMD. Subject seated.

Audio display: Earphones on HMD, with vibratory sensations delivered by subwoofer mounted under chair.

Tracking: Polhemus Insidettrak for head tracking.

Navigation: None.

Object manipulation: None.

Virtual world: Passenger cabin in an airplane with outside graphics.

Training: None.

Experimental task: View airplane flight as passenger seated in left window seat over wing and looking out the left window. 6-minute flight.

Participants: 72 participants, attendees at a computer expo in San Diego; 30 males, 42 females; age range 18 to 73, mean age 36.4 years. 62 non-phobic, 10 phobic, based on the Diagnostic and Statistical Manual of Mental Disorders (4th Ed) criteria.

Presence measures: Reality Judgment and Presence Questionnaire, Δ skin resistance and Δ heart rate.

Person-related measures: 34-item True/False inventory Tellegen Absorption Scale (TAS), 28-item questionnaire Dissociative Experience Scale (DES).

Task-related measures: SSQ.

Findings: (1) Presence had a significant positive correlation with realism, TAS, and DES. Realism also had a significant positive correlation with TAS and DES.
 (2) Percentage change of skin resistance and heart rate each had a significant negative correlation with presence.
 (3) *SSQ score had a significant correlation with the DES, but not the TAS.*

[Wiederhold, 1998] Wiederhold, B.K., R. Davis, and M.D. Wiederhold. 1998. “The Effects of Immersiveness on Physiology.” In G. Riva et al. (Eds.), *Virtual Environments in Clinical Psychology and Neuroscience*, 52–60. Amsterdam: IOS Press.

Factors: Visual display (HMD, 3D monitor).

Computing platform: Intel microprocessor-based PC, with advanced audio and Diamond Monster-3D graphic cards. Software from Previ (Spain), VRHealth (Italy), Hanyang University (Seoul, Korea), and Virtually Better.

Visual display: Liquid Crystal MRG4 HMD. Subject seated.

Audio display: HMD headphones or speakers positioned next to monitor. Subwoofer mounted under participant’s chair.

Tracking: Polhemus Insidettrak for head tracking.

Navigation: None.

Object manipulation: None.

Virtual world: Passenger cabin in an airplane with outside graphics.

Experimental task: View airplane flight as passenger seated in left window seat over wing and looking out the left window. 10-minute flight.

Participants: 5 psychology doctoral-level students; 2 males, 3 females; age range late 20’s to 40’s. No prior experience with VE. One participant had a fear of flying, meeting DSM-IV criteria for a specific phobia.

Study design: Within-subjects.

Presence measures: Wierderhold’s questionnaire, Δ skin resistance, Δ heart rate, Δ peripheral skin temperature, Δ respiration rate.

Findings: (1) For non-phobic participants, visual display had a significant positive effect on Δ skin resistance.
 (2) Visual display had no significant effect on Δ heart rate, Δ peripheral skin temperature, and Δ respiration rate.

[Witmer, 1998 (2)] Witmer, B.G. and P.B. Kline. 1998. "Judging Perceived and Traversed Distance in Virtual Environments." *Presence*, 7(2), 144–167.

Factors: Navigation (treadmill, joystick, passive teleportation), gender, distance cues (auditory tone every 10ft for every other segment, no cues), movement speed (1.2, 2.4 mph), texture density (2-ft, 4-ft tiles), traversed distance (10, 40, 80, 120, 160, 200, 240, 280ft).

Computing platform: SGI Crimson Reality Engine. VE modeled using Software Systems MultiGen and rendered using SGI Performer.

Visual display: Fakespace Labs BOOM2C display fitted to participant's head using a head strap, used in monochrome mode, stereoscopic with 1280 × 1024 pixels per eye with 70° overlap, maximum FOV 140°H × 90°V.

Tracking: Via BOOM2C.

Navigation: Only forward movement permitted. Movement via treadmill, joystick, or by being passively teleported by the experimenter.

Object manipulation: None.

Virtual world: Four test routes, each consisting of a series of 8 connected hallway segments. Hallways 10ft wide, 10ft high, varied in length (20, 50, 90, 130, 170, 210, 250, 290ft). Total length always 1210ft. Segments formed right angles with each other to form alternating series of left-right turns.

Training: Follow a practice route in the VE twice, practicing procedures and movement (latter at two speeds).

Experimental task: Traverse 4 test routes reporting traversed distance and time taken for each segment.

Participants: 72 university students; 36 males, 36 females; age <37 years. Participants had normal or corrected-to-normal vision, no other vision problems.

Study design: Within-subjects (movement speed, texture density, traversed distance), between-subjects (type of navigation, gender, distance cues).

Presence measures: 32-item Witmer-Singer PQ Version 2.0.

Person-related measures: Gender.

Task-related measures: *Rating of compellingness of movement.*

Performance measures: *Accuracy of estimates of distance traveled, relative error for each segment/route.*

Findings: (1) Navigation had a significant effect on presence, with treadmill users reporting more presence than joystick or teleport groups; who did not differ significantly.
(2) Gender had no significant effect on presence.
(3) Distance cues had no significant effect on presence.
(4) *Distance cues, movement speed, traversed distance, and 3 interactions (distance cues and movement speed, distance cues and traversed distance, movement speed and traverse distance) each had a significant effect on estimates of segment distance traveled and relative error, but type of movement, texture density, and gender had no significant effect.*
(5) *Distance cues, movement speed and gender each had a significant effect on estimates of total route distance, but type of movement had no significant effect.*
(6) *Type of movement had a significant effect on compellingness, with higher ratings given for treadmill than joystick, and both these higher than for teleporting.*

[Witmer, 1996] Witmer, B.G., J.H. Bailey, and B.W. Knerr. 1996. "Virtual Spaces and Real World Places: Transfer of Route Knowledge." *International Journal of Human-Computer Studies*, 45, 413–428. See also Bailey (1994).

Factors: Training type (real environment, virtual environment, verbal directions and photographs).

Computing platform:	SGI Crimson Reality Engine with single processor, 2 raster managers. Model generated using Software Systems MultiGen, rendered using Sense8 Corp. WorldToolKit.
Visual display:	Stereoscopic, 2-color Fakespace Lab BOOM2 with FOV 140°H × 90°V, 1280 × 492 pixels per eye. Update rate 30–60Hz.
Tracking:	Head tracking using BOOM2 display.
Navigation:	Using BOOM2 display, user moves in direction facing, or backwards, at a constant speed by depressing buttons on display control handles.
Object manipulation:	None.
Virtual world:	Large, spatially complex office building. Texture maps derived from photographs of objects.
Training:	None.
Experimental task:	15-minute study of route directions and photographs of landmarks for a complex route, either with or without a map. Then 3 rehearsals of route in the VE, in the actual building, or verbally. All participants required to stop at and identify 6 destinations along the route. All participants tested in actual building. Office building approx. 117,950 square ft. Complex route (1,500ft) wound along corridors on 3 floors leading to 6 destinations in 2 office suites; 41 directional changes and 47 2-choice decision areas along route. Building areas included typical office furnishings, including fluorescent lights, wall paintings, and exit signs. Model included functional staircases and out-of-the-window views. Doors to accessible areas automatically opened when approached.
Participants:	20 participants; 10 males, 10 females.
Presence measures:	32-item Witmer-Singer PQ Version 2.0.
Person-related measures:	29-item Witmer-Singer ITQ Version 2.0. <i>Also gender.</i>
Task-related measures:	Kennedy SSQ.
Performance measures:	Route knowledge assessed using number of attempted wrong turns, route traversal time, misidentified destinations, distance traveled. Building configuration knowledge measured using a target triangulation technique (projective convergence providing consistency, accuracy, average distance error and average miss distance measures).
Findings:	<ol style="list-style-type: none"> (1) Route knowledge and configuration knowledge had no significant correlation with presence. (2) Simulator sickness had a significant negative correlation with presence. (3) <i>During route rehearsal, type of rehearsal had a significant effect on route learning, with slower route traversal times and more wrong turns for VE group than other two groups, which were not significantly different.</i> (4) <i>During route rehearsal, trial had a significant negative effect on route traversal time. Trial also had a significant interaction with type of rehearsal, such that the VE group showed a steeper learning curve with respect to route rehearsal time than the other two groups, which were not significantly different and, with respect to wrong turns, also a steeper learning curve than the symbolic group, which was steeper than that of the real group.</i> (5) <i>For training transfer, type of rehearsal had a significant effect on route learning, with the real group making fewer wrong turns than VE group, who made fewer wrong turns and took less time than the symbolic group.</i> (6) <i>For training transfer, type of rehearsal had a significant effect on route traversal time, with those in the real and VE groups taking less time than the symbolic group. (There was no significant difference between the real and VE groups).</i> (7) <i>Type of rehearsal had no significant effect on configuration knowledge.</i> (8) <i>Configuration knowledge as measured by accuracy and consistency on paper-based convergence test had a significant negative correlation with ITQ scores.</i> (9) <i>Gender had no significant effect on route learning, but a significant effect on configuration knowledge, with improved performance found for male participants.</i> (10) <i>SSQ scores had no significant effect on route or configuration knowledge.</i> (11) <i>Gender had no significant effect on SSQ scores.</i>

[Witmer, 1994a (1)] Witmer, B.G. and M.J. Singer. October 1994. *Measuring Presence in Virtual Environments*. Technical Report 1014. U.S. Army Research Institute for the Behavioral and Social Sciences. See also Lampton et al. (1995).

Computing platform: Two 486/DX50 MHz PCs with Intel Action Media graphics boards. VE developed using Sense8 Corp. WorldToolKit.

Visual display: Stereoscopic, color Virtual Research Flight Helmet HMD with FOV 83°H × 41°V, resolution 234 × 238 pixels per eye.

Tracking: Polhemus Isotrak for head tracking.

Navigation: Using joystick or spaceball.

Object manipulation: Using joystick or spaceball.

Virtual world: VEPAB VE, see [Singer, 1995] above.

Training: Explanation and demonstration of operation of control device.

Experimental task: Set of generic VEPAB tasks: Snellen Chart, color perception test, distance estimation, backing-up, hallway turns, figure 8 hallway, doorways.

Participants: 24 participants; 16 males, 8 females; age range 17 to 37, mean age 24 years.

Presence measures: 32-item Witmer-Singer PQ Version 1.0. Measured after each of two experimental sessions.

Person-related measures: 29-item Witmer-Singer ITQ Version 1.0.

Task-related measures: Kennedy SSQ.

Performance measures: Time to complete and accuracy of response to each task.

Findings:

- (1) Accuracy for the windows task had a significant negative correlation with PQ Total, Control Responsiveness, Interface Awareness, and Control Distraction subscales. Accuracy for the bins task had a significant positive correlation with PQ Total, Control Responsiveness, Involvement, and Control Distraction subscales. Accuracy for the slide task had a significant positive correlation with PQ Total, Control Responsiveness, Sensory Exploration, Involvement subscales. Accuracy for the dial task had a significant positive correlation with PQ Control Responsiveness, Involvement subscales. Accuracy for the choice reaction time task had no correlation with PQ Total or any subscales.
- (2) Time to complete for the windows task had a significant negative correlation with PQ Total, Control Responsiveness, Interface Awareness, and Control Distraction subscales. Time for the bins task had a significant negative correlation with PQ Total, Control Responsiveness, Involvement, Control Distraction subscales. Time for the slide task had a significant negative correlation with PQ Total and all subscales. Time for the dial task had a significant negative correlation with PQ Involvement subscale. Time for the choice reaction task had a significant negative correlation with PQ Total, Control Responsiveness, Sensory Exploration, Involvement subscales. Time for the simple reaction time task had a significant negative correlation with PQ Total, Control Responsiveness, Sensory Exploration, and Involvement subscales.
- (3) SSQ Total and all subscales had a significant negative correlation with PQ Control Responsiveness.
- (4) PQ scores had no significant correlation with ITQ scores.
- (5) *Performance had no significant correlation with ITQ total.*

[Witmer, 1994a (2)] Witmer, B.G. and M.J. Singer. October 1994. *Measuring Presence in Virtual Environments*. Technical Report 1014. U.S. Army Research Institute for the Behavioral and Social Sciences. See also Lampton et al. (1995).

Computing platform...Training: As above in [Witmer, 1994a (1)].

Experimental task: Set of generic VEPAB tasks: flying-thru-windows, elevator, bins, slide/dial manipulation, simple/choice reaction time, stationary/moving target acquisition.

Participants...Performance measures: As above.

Findings:

- (1) Accuracy for the windows task had a significant negative correlation with PQ Total, Control Responsiveness subscale. Accuracy for the bins task had a significant positive correlation with PQ Sensory Exploration, Involvement subscales. Accuracy for the slide task had a significant positive correlation with PQ Total, Control Responsiveness, Sensory Exploration subscales. Accuracy for the dial task had a significant positive correlation with PQ Sensory Exploration, Involvement subscales. Accuracy for the choice reaction task had a significant positive correlation with PQ Total, Sensory Exploration subscale.
- (2) Time to complete the windows task had a significant negative correlation with PQ Total, Control Responsiveness, Interface Awareness subscales. Time to complete the bins task had no significant correlation with PQ Total or any subscales. Time for the slide task had a significant negative correlation with PQ Total, Sensory Exploration subscale. Time for the dial and choice reaction tasks had no significant correlations with PQ Total or any subscales. Time for the simple reaction task had significant negative correlation with PQ Involvement subscale.
- (3) SSQ Total had a significant negative correlation with PQ Total, Control Responsiveness, Sensory Exploration, and Involvement subscales. SSQ Nausea, oculomotor, and disorientation subscales had a significant negative correlation with PQ Control Responsiveness subscale. SSQ Nausea subscale had a significant negative correlation with PQ Sensory Exploration subscale. SSQ Oculomotor subscale had a significant negative correlation with and PQ Involvement and Control Distraction subscale.
- (4) PQ scores had no significant correlation with ITQ scores.
- (5) *Performance had no significant correlation with ITQ total.*

[Witmer, 1994b (1)] Witmer, B.G., J.H. Bailey, and B.W. Knerr. April 1994. *Training Dismounted Soldiers in Virtual Environments: Route Learning and Transfer*. U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors: Training type (VE, building, symbolic), map (present, absent).

Computing platform: SG Crimson Reality Engine. Multigen by Software Systems and WorldToolKit by Sense8 Corp.

Visual display: Fake Space Lab 2-color Boom2 display.

Audio display: None.

Tracking: Via Boom2 display.

Navigation: Via Boom2 display.

Object manipulation: None.

Virtual world: Representation of first 3 floors of a building in the Central Florida Research Park, ~117,950 sq. ft. Many of the office furnishings were included in offices and work spaces. Doors to modeled areas opened automatically when within 10ft distance, and remained open for several seconds.

Experimental task: Study of designated route for 15 minutes using step-by-step directions, landmark and destination photos and depending on condition, map with route marked. Followed by 3 route rehearsals in appropriate condition. Performance evaluated in a real-world transfer test, following the learned route and identifying 6 specified destinations along the route. Then participant taken to the lobby on third floor and asked to exit the building as quickly as possible using the most direct route. Third task required estimating direction and distance to 4 goal locations.

Participants: 60 college students; age range 18 to 53 years.

Study design: Between-subjects.

Presence measures: Witmer-Singer PQ

Task-related measures: Kennedy SSQ.

Performance measures: Number of wrong turns, number of misidentified destinations, time to reach each destination and entire route, number of steps taken along route. Also time taken and distance traveled to exit building, and, for location task, consistency, accuracy, average distance error, average miss distance.

Findings: (1) Measures of route learning had no significant correlation with presence.
(2) Measures of configuration knowledge had no significant correlation with presence.
(3) SSQ scores had a significant negative correlation with presence.
(4) *Training type had a significant effect on route learning, with best performance for building training, followed by VE training, with symbolic training worst. Map and gender had no significant effect on route learning.*
(5) *Training type and map had no significant effect on configuration knowledge, though males performed significantly better than females.*

[Youngblut, 2003] Youngblut, C. and O. Huie. 2003. "The Relationship between Presence and Performance in Virtual Environments: Results of a VERTS Study." In *Proc. IEEE Virtual Reality 2003 Conference*, 22–26 March, Los Angeles, CA. 277–278.

Factors: Visual display (rear projection screen, desktop), training type (VE-based training and study of written procedures, study of written procedures only).

Computing platform: Pentium III 700 MHz PCs, with NVUDIA GeForce 3 graphics accelerators. Reality by Design, Inc. CHEM-BIO SVS2 software developed using SimStorm.

Visual display: Proxima 9260 rear projector with 9.5 × 7.5ft. DA-LITE projection screen, enclosed in curtained-off area.

Audio display: Voice-activated radios for team communication, speakers for sounds of alarms.

Tracking: Tracking of head (vertical motion only) and mock chembio monitor using Intersense Corp. IS-600 Series Precision Motor Trackers.

Navigation: Using belt-mounted, custom 3D joystick with rear projection screen interface, table positioned Microsoft Sidewinder Precision Pro 6DOF joystick with desktop interface.

Object manipulation: Using joystick controls and mock-up chembio monitor.

Virtual world: Three IDA's Virtual Cities with sub-meter accuracy. One was a recreation of a warehouse on New York Pier 16, another was an office building in New York, the third was Penn Station. All included representative objects. No self-representation.

Training: 25 minutes study of written procedures, followed with 5-minute question-and-answer period. Participants in each VE group then received 10-minute demonstration and practice of the immersive or desktop interface.

Experimental task: VE participants also performed 2 practice missions to learn mission procedures for searching for chembio hazards in a designated area. 20 minutes each. Performance evaluated in a real-world transfer test, 30 minute time limit.

Participants: 35 student intern employees; 75% male; mean age 21 years.

Study design: Between-subjects.

Presence measures: 32-item Witmer-Singer PQ Version 1.0, 6-item SUS questionnaire.

Person-related measures: 29-item Witmer-Singer ITQ Version 1.0, gender, experience with video games and 3D computer games, experience with immersive VEs, knowledge of VE technology, Ekstrom's cognitive tests (visualization aptitude using Paper Folding test, spatial orientation using Card Rotation and Cube Comparison tests, visual memory using Map Memory test, spatial scanning using Map Planning test).

Performance measures: Sum of correctness and completeness scores for individual elements of mission procedures.

Findings: (1) Visual display had no significant effect on presence.
(2) SUS questionnaire scores had a significant positive correlation with performance. PQ scores were not correlated with performance.
(3) PQ and SUS questionnaire scores had no significant correlation.

- (4) PQ Total and all subscales had a significant positive correlation with visualization aptitude measured using the Card Rotation test. No relationship was found for SUS.
- (5) Spatial orientation, visual memory, and spatial scanning had no significant correlations with either PQ or SUS scores.
- (6) Gender had no significant effect on PQ or SUS questionnaire scores.
- (7) Game experience had a significant positive correlation with PQ Involved/Control subscale, VE experience and VE knowledge with SUS questionnaire scores.
- (8) *Visual display and training type had a significant effect on performance, with VE participants demonstrating better learning of mission procedures than those who only studied written procedures.*
- (9) *ITQ Total, Focus and Games subscales scores had a significant positive correlation with SUS questionnaire scores.*

[Youngblut, 2002] Youngblut, C. and B.M. Perrin. 2002. "Investigating the Relationship between Presence and Task Performance in Virtual Environments." Paper presented at *IMAGE 2002 Conference*, July 8–12, Scottsdale, AZ.

Factors:	Practice with interface (basic 2–3 minutes, extended additional 30 minutes).
Computing platform:	SGI Reality Monster. DVise software.
Visual display:	Virtual Research stereoscopic HMD, resolution 640 × 480, refresh rate 30Hz. Participant standing, free to walk as necessary for task.
Audio display:	Task statements prerecorded using Authorware on PC.
Tracking:	Ascension head and hand tracking.
Navigation:	Based on head movement.
Object manipulation:	3D mouse button used for grasping objects.
Virtual world:	Aircraft hangar with an entire F/A-18 aircraft. Self-representation as virtual hand.
Training:	For basic practice, written description of task and interface, and 2–3 minutes of familiarization with activities such as moving to an object, grasping and manipulating it. For extended practice, basic practice plus about 30 minutes of practice on a task different to that used in the study.
Experimental task:	24-step F/A-18 maintenance procedure involving the removal and replacement of the wing high-level fuel valve. The procedure is performed inside an access area in the wing and involves both physical obstructions (parts that must be removed to get to the fuel valve) and visual obstructions (even after the physically obstructing parts are removed, several of the fasteners holding the fuel valve cannot be seen through the access door). One practice run of the task in the VE, accompanied by verbal instructions. Training transfer tested on a physical mock-up.
Participants:	40 participants from Boeing staff; 27 males, 13 females; age range 20 to 64 years, mean age 40 years. Participants had normal or corrected-to-normal vision and no prior experience with aircraft maintenance.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 1.0, 6-item SUS questionnaire.
Person-related measures:	29-item Witmer-Singer ITQ Version 1.0, visualization aptitude using Paper Folding test, experience with relevant tools (e.g., fixing cars), age, gender, height, level of education, experience with video games and 3D computer games, experience with immersive VEs, knowledge of VE technology.
Task-related measures:	Kennedy SSQ, rating of fatigue.
Performance measures:	Paper-and-pencil knowledge test, time to complete task on physical mock-up, count of performance errors while completing training transfer test.
Findings:	<ol style="list-style-type: none"> (1) Practice with interface had no significant effect on SUS scores, and a significant positive effect only for PQ Interface subscale. (2) The only personal characteristic that had a significant correlation with SUS questionnaire scores was the ITQ Focus subscale, this was a positive correlation.

- (3) Age, gender, 3D-computer game experience, and visualization aptitude had no significant correlations with PQ scores. Level of education had a significant positive correlation with PQ Total and all subscales. Video game experience had a significant negative correlation with PQ Involved subscale. VE experience had a significant negative correlation with PQ Total and Involved subscale. Knowledge of VE technology had a significant negative correlation with PQ Total and Involved subscale.
- (4) SSQ scores and fatigue had no significant correlation with SUS questionnaire scores.
- (5) SSQ Oculomotor subscale had a significant negative correlation with PQ Total. SSQ Total and Oculomotor subscale each had a significant negative correlation with PQ Involved subscale. Fatigue had a significant negative correlation with PQ Interface subscale.
- (6) PQ Total and all subscale scores had a significant positive correlation with SUS questionnaire scores.
- (7) SUS and PQ Involved each had a significant negative correlation with count of performance errors. Other presence measures had no significant correlation with any other performance measures.
- (8) *Practice with interface had no significant effect on any performance measure.*
- (9) *Experience with relevant tools and visualization aptitude each had a significant positive effect on knowledge test scores and a significant negative effect on both training transfer tests. Gender had a significant effect on both the knowledge test scores and time taken for the training transfer test, with males achieving higher test scores and females taking less time. Video game and 3D computer game experience each had a significant negative effect on time taken for the transfer test.*
- (10) *SSQ and fatigue had no significant effect on any performance measure.*

[Zimmons, 2003] Zimmons, P. and A. Panter. 2003. "The Influence of Rendering Quality on Presence and Task Performance in a Virtual Environment." In *Proc. IEEE Virtual Reality 2003 Conference*, 22–26 March, Los Angeles, CA. 293–294.

Factors:	Texture mapping (combinations of high/low texture resolution and high/low lighting quality plus additional condition of black and white grid texture).
Computing Platform:	Rendering with ATI Radion 8500 with dual video outputs. Lightscape for lighting computations.
Visual display:	Virtual Research V8 HMD, with 640 × 480 pixels per eye.
Auditory display:	None.
Physiological devices:	ProComp+ worn as backpack for heart rate and skin conductance measurement.
Tracking:	3rdTech optical tracking system for head and hand tracking.
Navigation:	Using joystick.
Object manipulation:	Using joystick with trigger to pick up and drop objects.
Virtual world:	2-room virtual world, consisting of a training room and pit room.
Training:	Practice using VE interface in the training room, including picking up and dropping objects on a target.
Experimental task:	Drop four objects on targets in a virtual chasm.
Participants:	55 college-age participants; 25 male, 30 female; with stereo-vision, no prior VE experience, no precluding medical conditions, no significant phobia of heights.
Presence measures:	SUS Questionnaire, Δheart rate, Δskin conductance.
Person-related measures:	Gender. <i>Also high-anxiety questionnaire, Guilford-Zimmerman spatial orientation test.</i>
Task-related measures:	<i>Kennedy SSQ.</i>
Task performance measures:	<i>Accuracy of dropping balls on targets.</i>
Findings:	(1) Texture mapping had no significant effect on any presence measure. (2) Gender had no significant effect on presence.

- (3) Texture mapping had no significant effect on task performance.*
 - (4) SSQ scores and height anxiety had no significant correlation with texture mapping, but a significant correlation with gender.*
 - (5) Spatial ability had no significant correlation with task performance, but a significant difference for gender.*
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13. SUPPLEMENTARY NOTES					
14. ABSTRACT Much attention has been focused on feeling a sense of presence in a virtual environment (VE). The potential importance of presence is based on an assumption that increasing the sense of presence experienced in a VE leads to an improvement in task performance. This document summarizes the results of experimental work that has been performed. Nearly 70 different measures of presence are identified, and over 100 studies that investigated various issues about the presence construct are cited. There are 83 findings regarding a relationship between presence and task performance. Roughly half of these show a significant correlation—most in the expected direction. As yet, there is no evidence whether the relationships that do exist are causal in nature. Nonetheless, some conclusions are clear. Despite a decade of research, the role of presence in VEs is still unclear. No commonly agreed theory of presence—much less common measures for this construct—exist. Some evidence exists that particular technological, task, and personal characteristics can influence the extent of presence experienced in a VE. However, the critical question of whether manipulating presence can achieve improved task performance remains unanswered.					
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